THE

ELECTRIC JOURNAL

VOL. V

JANUARY-DECEMBER

1908

Published by

THE ELECTRIC CLUB

PITTSBURG, PA.

THE ELECTRIC JOURNAL

THE ELECTRIC JOURNAL is published by The Electric Club. The Journal is unique in having the support of an active electrical society which numbers among its members the engineers of a large electric company, as the Club is composed principally of men connected with the Westinghouse Electric & Manufacturing Company.

The aim of the Journal is to be direct, definite and practical, and to be recognized by progressive electrical men as one of the indispensable aids to effective engineering work.

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PUBLISHED BY

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THE

ELECTRIC JOURNAL

VOL. V. JANUARY, 1908 NO. 1.

The Journal for 1908

"To be of use to its readers; to be of real assistance to electrical engineers, present and future, and to be an active force in accelerating the progress and advancing the best interests of the electrical engineering profession,—these are the aims and ambitions with which we enter the New Year." With these words we entered the year 1907—they are fitting for the coming year as well.

A peculiar relation exists between the editor and the reader. It is an intimate one—and yet it is usually a distant one. The editor plans his articles to suit his readers, he tries to see their needs and understand their point of view. His attitude is personal as well as professional, and yet he may really know scarcely any of the readers.

A writer may present an article which embodies the results of months of thought and work. It is a personal product, and he may write and rewrite to secure the clearest and most effective form. He imagines his audience before him, and he gains inspiration by anticipating their interest. The articles goes forth. It may be read by hundreds or thousands, and yet the author speaks to an audience in the dark—he knows not how his words are received and understood, nor does he even know that his audience is listening to what he says. He gets no response. Possibly subscription renewal is the reply of the reader. It does not discriminate. If it comes, it does not specify what has been satisfactory and appreciated. If it does not come, there is no indication of what is lacking or at fault.

The JOURNAL, however, is peculiarly fortunate in having a definite and accessible group of readers in the membership of The Electric Club. To meet the needs, both in material and form, of these rising young engineers gives a definite object at which to aim. This definiteness of purpose and the close relationship between the JOURNAL and these readers have been principal factors in shaping the development of the JOURNAL. But the Club members

are numbered by the hundreds, while the general readers of the JOURNAL run into thousands. The things which have been of special interest to the young engineer in the works of an electric company have interested others in many lines of electrical and engineering activity. Likewise there is a reciprocal interest. The problems of general engineering, the difficulties which arise in every day pracice, the questions which puzzle the man who is thrown upon his own resources, are all of direct interest to the young man who is laying the foundation for an engineering or operating career.

This is the point of view which has inspired The JOURNAL Question Box as a new means of enabling the JOURNAL more fully "to be of use to its readers," by bringing the editor and the reader into closer relations.

THE PUBLICATION COMMITTEE

Welding Steel Castings

One of the most important developments within the last few years in the mechanical design of machinery of all kinds is the progress which has been made in the use of cast steel. At first used sparingly for large castings of comparatively simple design and where exceptional strength was needed, its use has extended to castings of small size and complicated shape and in many instances it is chosen for the purpose, not of procuring exceptional strength, but of obtaining castings of comparatively light weight for a given service.

While its extended use has been made possible by advances which have been made in the art of casting steel, it cannot yet be said that for general purposes, steel castings are as reliable as iron castings. Expressed in different terms, it is more difficult to obtain a sound steel casting than it is one of iron. No matter how much care is taken in the preparation of moulds and in the pouring of the castings there is a liability of blow holes and mis-running at the high points in the mould which results in a comparatively large percentage of scrap. In the majority of instances these defects do not appear on the surface and both time and money is lost in machining before the defect becomes evident. Furthermore, it is usually the case that manufacturers are not provided with their own steel foundries, even though they may be equipped for the making of iron castings, hence there is a greater delay incurred in replacing a defective steel casting than is necessary in the case of a defective iron casting.

It is evident, therefore, that all users of steel castings will be interested in the article by Mr. C. B. Auel appearing in this issue,

which describes a simple and practicable method for the application of electric welding to the repairing of defective steel castings. The method described involves very little special equipment, and its cost of installation is small compared with the saving in time and expense which result, provided there is sufficient work to keep the plant occupied. Not only is there a material saving in the replacal charge for scrapped castings, but one of the most important benefits is the ability to put the castings into useable shape, thus avoiding the delay incident to replacing them.

Furthermore, it is evident that the process, as described by Mr. Auel, is adaptable to many other uses than that which has been described.

ALEXANDER TAYLOR

Voltmeter Compensation for Drop

Regulation of voltage on constant potential supply circuits is one of the most important problems presented to the engineer who designs a plant, as well as to the one who operates it. Efficiency in apparatus and in transmission, even affecting as it does the cost of power, is in many ways secondary in importance to regulation. Lower efficiency usually involves simply the burning of a little more coal, but poor regulation affects the quality of the service, and may greatly reduce its commercial value. It may result in either low candle power or high lamp breakage, it may affect the speed, the capacity, the temperature, or the starting torque of motors; it may cause an otherwise satisfactory service to be a severe burden to the apparatus and to the patience of those who are dependent upon it.

Various articles in the JOURNAL have presented the elements which determine the drop in alternating-current circuits. The problems are fairly simple to those who are familiar with the theory involved, but are perplexing to those whose knowledge is gained only from observation of phenomena that are not understood. Even when the theoretical elements are known it is another problem to overcome the conditions they present. One factor in the solution is the securing at the operating station of an indication of the actual voltage at the point of supply, *i. e.*, at the end of circuits consisting of transmission lines and transformers with their several resistances and inductances whose effects are often varied by the ever-puzzling power-factor. The desired indication, however, is given by the compensation, described by Mr. Nesbit in this issue of the JOURNAL.

Mr. Nesbit says that he was led to write the article describing

the compensator because he found that many central station men do not really understand its function and value, and some of those who have installed it have not secured satisfactory results. The calculations which have been considered necessary in order to make proper adjustments are not readily made by the average central station men, and indeed the conditions are frequently not of the simple kind that admit of ready calculation. The theory may be fairly simple, but the constants may be difficult to determine. It has been found, however, that, by a simple rule, the instrument can be adjusted by trial. The principle involved and the practical methods of adjustment which he has proposed and satisfactorily used are described by him and illustrated for the benefit of others who are troubled by unsatisfactory regulation of their circuits.

An article dealing with the practical difficulties involved in the use of the apparatus will be more serviceable than a lot of formulæ would be, especially in many cases where it is difficult to apply them. Cut-and-try methods of adjustment are useful if intelligently applied, and Mr. Nesbit shows how to apply them to this case.

CHAS. F. SCOTT

THE COS COB POWER PLANT OF THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD

E. H. COSTER

THE power plant that supplies the motive power for the electrical divisions of the New York, New Haven & Hartford Railroad between Stamford, Conn., and New York, is situated on the west bank of the Mianus River, near Long Island Sound, and south of the new steel railroad bridge that spans the river at the village of Cos Cob. The channel of the Mianus River at this point is deep and wide enough for coal barges to be towed to the dock that has been built some five hundred feet from the power plant. As the neighborhood is a residential one, with cottages on both sides of the river, the architecture of the power house building is of a very different kind from that of the ordinary power house so as not to spoil the appearance of the district, and a mechanical draft plant with low chimney was adopted to avoid the tall chimneys that usually form part of power house architecture. The building is a comparatively low one of the California mission style, built of concrete blocks, with a red tile roof. The mission style was adopted, not because it is especially suitable for power houses, but because the form of building developed by the lay-out of the machinery lent itself to the mission style of treatment.

The site for the foundation of the building is of native rock, thus giving the best of foundations for building and machinery. The rock that had to be excavated made excellent material for concrete work, which fact led to the adoption of concrete block as the building material for the walls. The railroad company's property was large enough to give ample space for installing a stone crusher and concrete block plant, and all the blocks, water tables, lintels, sills, coping and the stones for the arches over the large windows were manufactured on the site.

The foundation walls up to the main floor of the building were made of monolithic concrete on which the water table was set. The walls were then carried up of hollow blocks. To prevent condensation from taking place in the winter on the underside of the roof, which condensation might damage the machinery below, three-inch I-beam purlins were used, with the space between them filled with cinder concrete. Furring strips were then nailed to the cinder con-

crete and the tile lath to the furring. The roofing tile was then laid in the ordinary way.

The building is made of fire-proof material throughout, the window frames and sash being of cast iron glazed with wire glass. All the floors are of reinforced concrete slabs on steel floor beams and girders. The only woodwork in the building is that in the doors, which is, however, fireproofed by being kalomein covered.

LAYOUT OF PLANT

The plant is divided into two parts in the usual way, the engine room and switchboard galleries being to the south, and the boiler room and fan room to the north.

On the main floor of the engine room there are three 750 kw turbo-generators, with space provided for a fourth unit, which is shortly to be installed. Two steam-driven exciter units complete

VIEW OF COS COB POWER PLANT AND COALING DOCK

the machinery on the main floor. There is sufficient floor space between the turbo-generators to give ample room for dismantling and assembling the machinery. An electric traveling crane runs overhead.

In the basement below are the surface condensers, circulating pumps, hot well pumps and dry vacuum pumps. Below the basement floors are two large flumes, one for the intake, and one for the overflow of the circulating pumps. As the variation of the water level in the Mianus River between high and low tide is about seven feet, the intake flume had to be carried down to a depth sufficient to supply the pumps with water at any stage of the tide. As the channel in the Mianus River is about five hundred feet from the power house, with mud flats intervening between shore and channel, a timber flume was constructed below the level of the water at low tide to connect the channel with the concrete flume under the

engine room. The entrance to this flume is located under the coal dock, where heavy screens are provided to prevent seaweed and other floating matter from entering the flume. A derrick is provided on the dock above to haul out the screens when they are to be cleaned.

On the south side of the engine room on the main floor and on the gallery above are located the switching apparatus, with the lightning arresters in a compartment by themselves over the gallery. The bus structure and the field rheostats for the main generators and the transformers for the station power circuits are located on the main floor and the switches, instrument board, exciter board and auxiliary board for controlling the lighting and power circuits in the station are in the gallery, as well as the transformers for the station lighting.

On the main floor of the boiler room are two rows of boilers, with the firing floor running down the center of the room. The boilers are grouped in batteries of two. The room is designed for sixteen boilers or four batteries on either side of the firing floor. At present twelve boilers are installed. At the rear of each row of boilers runs a main flue and back of each flue the economizers are located, one economizer to each group of four boilers. The gases from any of the eight boilers on one side, therefore, can pass through either economizer on that side of the boiler room.

In the center of the boiler room above the boilers is the fan room with four mechanical draft fans all discharging into a common stack. Two up-takes, one from each side of the boiler room, connect the outlets of the economizers to a chamber or connecting flue between the four fans. This design makes it possible to run any group of boilers with any of the four fans. Dampers have been so arranged in the flues that any economizer can be cut out and the gases taken direct from boiler to fan. In the same way each fan is provided with dampers so that any fan can be cut out of service for inspection and repairs. Dampers are also provided to enable the flues to be cleaned whenever necessary.

All the boilers are provided with Roney mechanical stokers and each group of four boilers is equipped with a stoker engine to operate the stokers. In case of a breakdown, one stoker engine can operate the stoker for eight boilers, and a suitable piece of shafting and the necessary couplings are provided to connect the stoker shafting of two groups.

The basement of the boiler room is divided into three sections; a

pump room under the firing floor in the center of the building; two ash tunnels, one under each row of furnaces, and thirdly, an open basement under the east side of the boiler room in which are located the machine shop, feed water storage tanks and toilet and locker rooms for the boiler room crew. Under the west side of the boiler room there is no basement, the boiler settings and flue walls resting directly on the rock foundation.

In the pump room are located the boiler feed pumps, the house service pump, the fire pump and the feed water heater.

In the ash tunnels narrow gauge tracks are installed on the concrete floor, on which are run the ash cars for removing the ashes from the ash hoppers under the furnaces to the outside of the building.

THE COAL SUPPLY

The plant is supplied with coal, both by water and by rail. To

COS COB POWER PLANT AND RESERVOIR

receive the coal coming in barges a coal dock was built at the edge of the channel of the Mianus River and a coal tower with coal crusher and hoisting outfit was installed. The coal tower is connected to a receiving hopper above the boilers at the south end of the boiler room by a steel trestle. On the trestle there is a cable railway to convey the coal from the tower to the receiving hopper. In the boiler room below the receiving hopper but above the boilers, there are two flight conveyors running the full length of the room. Two mechanical feeders deliver the coal from the hopper to the flight conveyors. Each flight conveyor serves the eight boilers on its side of the boiler room. As the coal is moved from the south end to the north end of the boiler room, it successively fills the spouts to the boilers and any coal that passes over the spout to the last boiler in

the row is discharged by a ninth spout into a coal bunker below the boiler room floor at the north end of the room.

It is intended to run the hoisting machinery on the dock and the cable railway only during the daytime, and the surplus coal delivered little by little during the day to the bunker below the floor is to be used for firing the boilers during the night. To empty the bunker of its supply of coal a tunnel was built, the roof of which formed the bottom of the bunker. Gates were provided in this bottom and a bucket conveyor was installed which carries the coal, when it is discharged from the bunker, up to a hopper over the north end of the flight conveyors. Two mechanical feeders discharge the coal from this hopper to the upper trough of the flight conveyors. The coal is carried to the south end of the upper troughs and is then discharged through chutes to the lower troughs. The coal is then fed to the boilers as already described.

The rail coal is provided for by a siding at the north end of the boiler room with a concrete hopper under the track into which the coal is discharged from the cars. The coal from this hopper is passed through a coal crusher and then delivered to the bucket conveyor in the tunnel under the coal bunker. From the bucket conveyor the coal is delivered to the flight conveyors in the manner just described or it is stored in the bunker through chutes carried down through the boiler room floor from the upper run of the bucket conveyor.

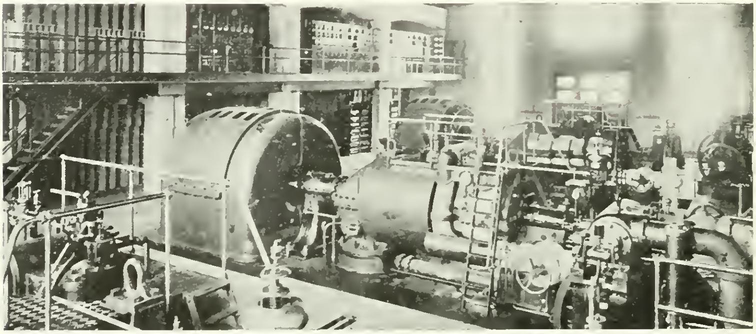
It will be seen from the above description of the coal handling machinery that in this plant the coal barge and the railroad cars form what is equivalent to the usual overhead storage bunker. The design of the coal handling machinery has therefore been to deliver coal to the boilers from either barge or railroad car as required by the stokers.

BOILERS

The boilers are of the Babcock & Wilcox type, provided with superheaters and have the three exposed sides of each battery enclosd with sheet-iron casing outside the brick settings. This type of setting has been adopted to prevent, as much as possible, the air leaks that develop through cracks in the brick settings. This feature is especially important in a plant with induced draft, as every leak increases the load on the fans and consequently the steam consumption of the fan engines.

The steam from the boilers is maintained at a constant pressure

by pressure regulators, one on each fan engine, which vary the speed of the fans and thus the draft in the flues as the load varies. The superheated steam is delivered from the boilers to the turbines and the auxiliary machinery by two main headers running above the boilers and supported from the roof beams. To make these mains as flexible as possible for expansion and contraction each main takes the steam from four boilers on the east and four boilers from the west side of the firing floor, making an S-shaped curve as it passes from one side to the other. The two mains are carried at different levels so as to cross each other in the center of the boiler room below the draft fans. At the south end of the boiler room the two headers pass through the partition wall into the engine room and drop down



VIEW OF TURBINES, GENERATORS AND SWITCHBOARD

below the engine room floor into a common header, from which the branches to the turbines and to the auxiliary steam main are taken.

With the exception of the fan engines, stoker engines and the engines operating the scraper drives on the economizers, all the auxiliaries in the plant are operated by superheated steam. Besides the auxiliary steam main with its two terminals connecting to the main steam header in the engine room basement, there is a second auxiliary steam main in the boiler room for saturated steam. In addition to supplying steam to the fan, stoker and economizer engines, this main forms a duplicate main for supplying steam to the boiler feed pumps.

CONDENSERS

The exhaust steam for each turbine is carried down into a surface condenser located between the concrete foundations of the turbines. In addition there is a branch pipe provided with an hydraulic-

ally operated exhaust relief valve connecting to the atmosphere, which makes it possible to run the turbines non-condensing in case of emergency.

Each condenser is provided with a hot well, from which the condensed water runs by gravity to the hot well pump below it on the basement floor. By means of a float and lever and a special steam valve the speed of the hot well pump is regulated to keep the water in the condenser hot well at a constant level. The water from the hot well pumps is discharged through a common main into two hot well tanks in the boiler room basement. Into these tanks there is also discharged the water used in cooling the bearings on the turbines and sealing the turbine glands, and any other waste water that has not come in contact with oil.

BOILER WATER SUPPLY

In ordinary running the boiler feed pumps draw their supply through these tanks. The make-up water coming from the outside supply enters through valves operated by floats, thus keeping a constant head of water in the tanks.

The boiler feed pumps, which are three in number, have each two suction connections, one to the hot well tanks and one to the outside supply. Each feed pump is provided with a pressure regulating valve, so that the pump slows down or is stopped automatically as the water tender closes the feed valves to the different boilers. The opening of the same valves starts up the pumps again.

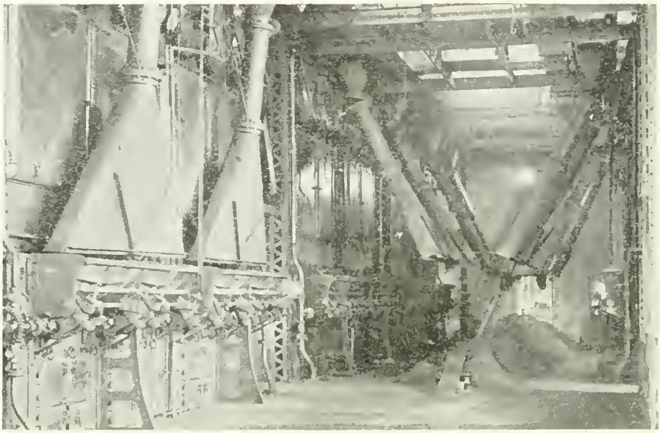
The water from the feed pumps is delivered into two pressure mains and is first discharged into a closed feed water heater which is supplied with steam from the exhausts of all the auxiliary machinery. The exhaust pipes are brought together into one exhaust steam main, which discharges into the feed water heater. The steam space in the heater is in free connection with the outside atmosphere, thus preventing any back pressure on the auxiliary engines. The feed water heater was proportioned to condense the average amount of exhaust steam under ordinary conditions. The feed water is next distributed through two pressure mains between the economizers that are in service and the temperature of the water is brought up as high as possible by heat absorption from the flue gases. The economizers therefore effect two different functions. First, they increase the temperature of the water, and second, they decrease the temperature and therefore the volume of the flue gases and hence the load on the mechanical draft plant. From the economizers the feed water

enters the distributing loop in the pump room from which all the boilers are fed and thus the circuit through which the water passes from the boiler to turbine and back from turbine to boiler is completed.

All the piping between the boiler feed pumps and the boilers is installed either with duplicate mains or with loops to prevent a breakdown or leak in one section of the piping affecting the feeding of the boilers.

CONDENSER AUXILIARIES

The circulating pumps in the engine room basement are of the centrifugal type driven by single acting compound engines. Each



VIEW OF BOILER ROOM

engine shaft is extended to carry the runner of the centrifugal pump and there is no bearing on the pump itself, the weight of the runner being carried by the engine bearings. The engine shaft passes through a stuffing box on one side of the pump housing. The pumps and their engines are erected on a heavy concrete slab which forms the cover of the intake flume, the suction pipes dropping down into the flume through openings provided in the slab. The suction pipes are not provided with foot valves, the pumps being primed each time they are started up.

The method of priming the pumps is as follows:—The highest point on the discharge pipe from each pump is connected to a common priming pipe that is connected to all three dry vacuum pumps. Between the discharge pipes and the dry vacuum pumps a riser is

installed going up to barometric height above the highest point on the water pipe to prevent water being carried over into the air cylinders of the dry vacuum pumps. Furthermore, to prevent any water that may be entrained by the air from passing into the dry vacuum pumps, a separator is provided at the highest point of the barometric riser. A quick closing valve is located on each priming pipe close to the water pipe so that the priming line can be shut off as soon as a pump is primed. With this system of priming any pump can be primed by any dry vacuum pump.

The dry vacuum pumps are of the two stage type and are driven by single cylinder Corliss engines, the two air cylinders and the steam cylinder being placed in line on a single bed plate. The air discharge from each dry vacuum pump is connected into the free exhaust pipe located in the engine room basement.

OILING SYSTEMS

To provide an adequate amount of oil for the turbines and other machinery a very complete gravity oil system has been arranged. On a platform in the south end of the boiler room a large steel tank for engine oil has been installed, with a smaller tank for crank case oil by its side. The oil in the engine oil tank has sufficient head to flow by gravity to the oiling system of the turbo-generators and from thence to the oil filter and tank in the west end of the engine room basement. From the tank under the filter the oil is pumped back into the oil pressure tank in the boiler room and starts anew on its circuit. The oil is thus filtered each time it runs through the turbine oiling system. The engine oil is further distributed to different points in the building within convenient distance of the machinery where the oil trays and cocks are provided. To fill this oiling system a platform was installed in the engine room basement near the oil filter tank from which barrels of oil can be emptied by gravity into the filter tank and from thence pumped into the pressure tank.

The crank case oil tank which provides oil for the lubricators on the different engines is filled from the same platform as the engine oil tank. The crank case oil is, however, not circulated in a loop like the engine oil. The method of filling the pressure tank is therefore different. A receiving tank is suspended underneath the platform and the oil barrels are emptied into it. When the tank is full the inlet valve is closed and the oil is forced by compressed air into the pressure tank in the boiler room.

The same method is employed in filling the cylinder oil pressure tank located above the fan room floor. A second receiving tank is provided under the platform in the engine room basement into which the barrels containing cylinder oil are emptied. The cylinder oil runs by gravity through a complete pipe system to all the different cylinder oil pumps on the auxiliary machinery.

The overflow from the crank cases of the different engines is carried to a separating tank in the engine room basement and here the oil and water are gradually separated from each other. The oil thus reclaimed is pumped to the crank case lubricators on the engines and returned to the crank cases from time to time.

It will thus be seen that the lubricating oil necessary for the different parts of the machinery flows by gravity through a complete system of piping to its destination.

ELECTRICAL EQUIPMENT

The generators are of the rotating field type, each generator being enclosed in a cast-iron casing for ventilating purposes. The generators have a three-phase winding, although the railroad is operated by single-phase current. This construction was made necessary because there is a considerable three-phase load for other purposes.

To supply outside air for the proper ventilation of the generators two air chambers have been arranged in the basement under the switchboard gallery and louvres have been installed instead of windows along the south wall. The space under each generator between the foundations has been enclosed with brick and concrete and connected to one of the air chambers by a large air duct of brick and concrete. The air after passing through the generator is discharged into the engine room basement. In these air chambers and air ducts the cables from the generators to the electrically operated oil switches are carried, the switches being directly above the air chambers in the gallery. In this way all the generator leads are confined to two enclosed spaces which can be kept locked thus protecting the cables from any outside injury. The air ducts connecting the air chambers with the generators are high enough for a man to stand upright in them so that there is ample room for inspecting or repairing the cables.

The space occupied by the electrical apparatus on the main floor is enclosed by an iron grating, thus preventing any unauthorized persons from coming too near to the apparatus, and also protecting the apparatus itself from outside injury.

There are two sets of bus-bars installed in parallel structures of brick and soapstone and divided into sections provided with disconnecting switches. This design makes it possible for each generator to be operated independently of the others practically as if it were in a separate power house. On this floor also are located the generator field rheostats and the step down transformers for the power circuits in the building and out to the coal dock.

On the gallery and directly over the two parallel bus structures the oil switches are located in two rows. In front of them are the instrument and exciter boards so located that the operator has an unobstructed view of the engine room floor and the machinery upon it. The transformers for the station lighting are also located on the gallery. To supply the necessary current for operating the oil switches a storage battery was installed in the engine room basement. The battery room is ventilated through windows to the outside air.

The switchboard is of the panel type and is in two sections;—the main switchboard controlling the generators, exciters and outgoing feeders, and the auxiliary switchboard controlling the various lighting and auxiliary circuits in the station. All the high-tension oil circuit breakers are solenoid-operated and are remote-controlled by small drum type switches on the switchboard.

The governors of the turbines may be regulated by means of small drum-type switches on the board, thus facilitating synchronizing and the proper division of load between the machines.

Owing to the fact that from this station single-phase current is distributed to railway circuits and also three-phase current to supply transformers which may have grounded neutrals, the oil circuit breakers are electrically interlocked so that it is impossible to parallel the two sets of bus-bars, the normal method of operation being to supply the three-phase lines from one set of bus-bars and the railway feeders from the other set.

Each generator panel is equipped with ammeters, indicating wattmeter, power-factor meter and field ammeter. The load panel is equipped with an ammeter and integrating wattmeters. The various feeder panels are equipped with ammeters and time limit relays, a separate integrating wattmeter being provided for the local service panel in order that proper record of the distribution of power may be kept.

All of the direct-current and low-tension switches for the exciter and auxiliary circuits are hand-operated knife switches,

mounted on the switchboard, except the equalizer switches for the exciter circuits, which are mounted on pedestals near the machines.

Two Tirrill regulators are provided for the exciter units, each having capacity sufficient for all excitation. Either Tirrill regulator can be connected to any of the four high-tension bus sections for the regulation of the voltage. Furthermore, either regulator is capable of controlling any or all of the exciters and can be connected to either exciter bus.

In the south-east corner of the gallery is located the chief engineer's office equipped with the different recording instruments. The feeder cables go out to the line from a chamber above the center of the gallery and in this chamber all the lightning arresters are installed.

The building is well lighted by incandescent and Cooper-Hewitt lamps. The latter are used for the general lighting of the engine room and of the firing floor of the boiler room.

A well equipped machine shop has been installed in the boiler room basement to take care of the ordinary repairs that are required to be done in a power house of this size. The shafting for the tools is driven by an electric motor, which receives its current from one of the power circuits.

SIGNAL SYSTEM

To facilitate the operating of the plant there has been installed a very complete system of signals and speaking tubes. In the engine room besides the telephone switchboard in the engineer's office, there are two telephone booths, one on the switchboard gallery and one on the main floor. At each turbine there is a speaking tube from the main floor to the basement, so that the watch engineer can give orders to the man in charge of the pumps or vice versa, the latter can report any trouble to the watch engineer. For starting up or shutting down the main units or the exciter units the chief electrician calls the attention of the watch engineer by sounding a gong and then indicates what is to be done by electrically illuminated transparencies that become visible by the pressing of a button at the electrician's desk.

In the boiler room there is a speaking tube connecting the fan room with the firing floor, and both these points with the pump room. Electric bells give the signals between the starting rheostats of the two flight conveyors and of the bucket conveyor.

Besides these different signals there is an air whistle installed

in the boiler room to call by means of different signals the different men about the plant when they are not at their particular posts.

GENERAL WATER SUPPLY

For the general water service in the plant a house service pump is installed in the pump room which automatically fills a house tank situated above the fan room floor. From this tank water is supplied by different pipe lines to the turbine bearings and glands, to the water jackets of the fan bearings, to the water jackets of the dry vacuum pumps and to the toilet rooms and to the firing floor for wetting down ashes. With the exception of the water used for the two latter purposes, all this water is returned to the hot well tanks in the boiler room basement and is used for feeding the boilers.

In the pump room there is also installed an Underwriter's fire pump with fire lines to the engine room floor, to the boiler room firing floor and to the coal dock. This latter line is also used for washing the screens of the intake flume.

WATER STORAGE

To safeguard against the shutting down of the plant due to a break in the supply of water a large reinforced concrete reservoir has been built to the west of the plant. In the event of a break in the water main supplying the plant, the water in this reservoir is to be used while repairs are being carried on. As the plant runs normally as a condensing plant, only the make-up water and the service water have to be provided for. The reservoir rests on the native rock and the walls are made of monolithic concrete reinforced by a steel cable. The forms of the walls were erected and provided with hooks at given intervals on which the cable was hung. The cable became thereby a spiral shaped reinforcing, being continuous from the foundation to the top of the wall. After the concrete had set and the forms had been removed the inside of the reservoir was carefully water-proofed with hydrex felt and compound, the water proofing being protected by a veneer of brick.

With this reservoir full of water and with the many safeguards provided against shut-downs, it would seem safe to rely on the Cos Cob Power Plant for the trunk line railroad traffic it has been designed to operate.

The complete plant was designed and constructed for the Railroad Company by Westinghouse, Church, Kerr & Co., who are now finishing the plant by providing for the fourth unit.

ELECTRIC WELDING

C. B. AUEL

THERE are several distinct processes of electric welding in use at the present time, these being named, if not from the original investigators, at least from those who had most to do with demonstrating their feasibility; namely, Zerener, La Grange-Hoho, Thomson and Benardos.

In the Zerener process, an arc is drawn between two carbon electrodes and caused to impinge by means of an electro-magnet upon the metal to be welded—this process is sometimes known as the electric blowpipe method.

The process credited to La Grange-Hoho, otherwise called the "water pail forge," makes use of a wood tank filled with a suitable fluid into which is placed the positive terminal of an electric circuit. The metal to be forged or welded is connected to the negative terminal, dipped into the fluid and held there until a welding temperature has been reached. It is then removed and the forging or welding completed under a hammer in the usual manner.

In the Thomson or "incandescent" process, the metals to be welded are brought into intimate contact with each other, being thus held by metallic, spring-actuated clamps and in this position, completing an electric circuit. The resistance at the point of contact between the metals is such as to produce a welding temperature in a very few seconds, when the two metals are then further forced together automatically, and welded in so doing.

In the Benardos process an arc is drawn directly between the metal to be welded, which forms one terminal of an electric circuit, and a carbon electrode, which forms the other terminal.

It is the purpose to describe here in detail but this last mentioned process and only its application in connection with steel castings, pipes and plates, though it has a considerably wider range of usefulness.

APPARATUS

The outfit required for the welding of steel castings includes a direct-current source of supply, a rheostat, a carbon electrode and fire-clay or carbon blocks for moulding purposes. An enclosure should be provided in which to carry on operations, for the glare from the arc is very intense and would seriously interfere with any

other work in the immediate vicinity. The operator should have all parts of his body well covered (the clothing is quite sufficient), as even a few minutes' exposure to the rays will produce an irritating effect like sunburn upon the skin, resulting in a reddening and subsequent peeling of it with, however, no more serious consequences. For the head a canvas hood is generally used, being fitted with a small window of colored glass, through which the welding operation is watched without risk of injury to the eyes. The hands are usually protected by buckskin gloves provided with gauntlets to cover the wrists.

Current may be obtained from a 100 to 125 volt supply circuit or from an independently operated dynamo, or from a battery operated in conjunction with a dynamo or other supply circuit. An even higher voltage, say 220, may be used, but it is very wasteful of energy. Assuming that there will be sufficient welding to keep at

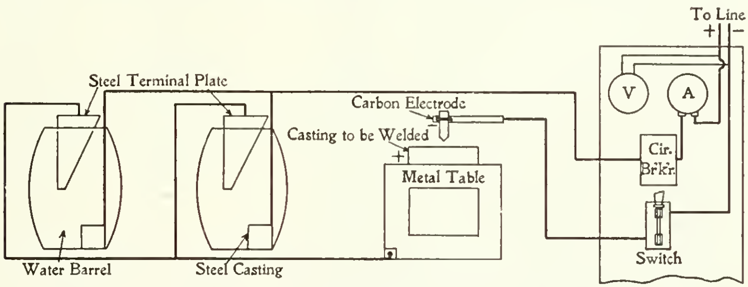


FIG. 1—DIAGRAM OF CONNECTIONS FOR ELECTRIC WELDING OUTFIT

least one man steadily employed, and taking into account the relative advantages and disadvantages of each of these several sources of supply, including first cost, subsequent maintenance, continuity of operation, simplicity and non-interference with other portions of the electrical plant, an independently driven dynamo is perhaps to be preferred. It is of the utmost importance that the supply be of ample capacity, for more failures may be traced to an inadequate supply than to any other one cause. The dynamo should, therefore, be of about 75 to 100 kw capacity at 100 to 125 volts, shunt or compound-wound, belt driven or direct connected; if the latter, a flexible coupling must be used, otherwise armature burn-outs are likely to be of frequent occurrence. With the dynamo should be provided a small switchboard having mounted on it the necessary instruments, voltmeter, ammeter, circuit breaker, field rheostat and switch. If the dynamo is driven by a motor instead of by an engine,

one or two additional instruments will be required for the control of the motor.

The rheostat may be of the grid type, though a very satisfactory one is easily constructed by using two water-tight barrels placed side by side. The positive cable of the circuit is carried from the dynamo to the switchboard and from the switchboard to the water rheostat. At the rheostat this cable divides into two smaller ones, these being fastened to separate triangular steel plates not less than one-fourth inch thick, suspended above the barrels by means of pulleys and counterweights, so that the plates may be readily lowered into or withdrawn from the barrels as occasion requires the adjusting of the water resistance. Similar cables are run down the inside of each barrel and one end likewise fastened to a heavy plate of steel, which lies on the bottom. The other end of each of these cables is attached to the casting to be welded or the cables may be fastened to a metal table and the casting simply laid upon it, always providing good contact is made. Discarded steel castings may be substituted for the steel plates in the bottom of the barrels. They should weigh about 20 or 30 pounds each and not occupy too much room. The negative cable of the circuit is carried from the dynamo to the switchboard and from the switchboard to the vicinity of the casting to be welded, where it is provided with a metal terminal and clamp, into which the carbon electrode is tightly fitted. In order to manipulate the carbon electrode during welding, the negative terminal is held in a wood insulating handle, to which is attached a shield of asbestos or other

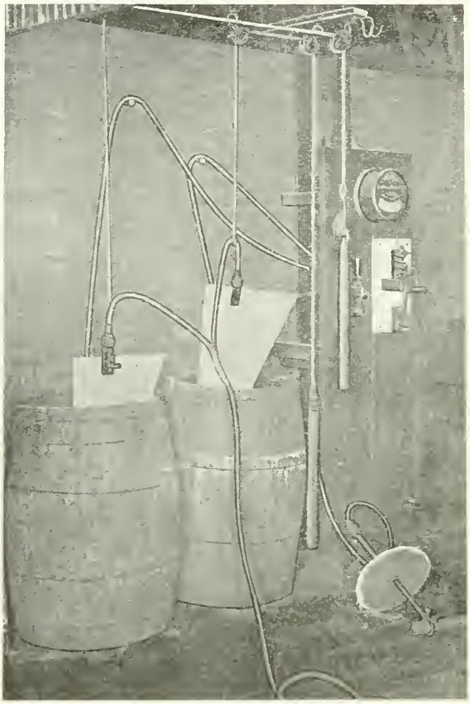


FIG. 2—WATER RHEOSTAT AND SWITCHBOARD

fireproof insulating material. The exact form of the terminal and clamp, the insulating handle and shield or the terminal plates of the water rheostat is immaterial, as is the method of attaching the cables to their respective terminals as long as good and sufficient contact is made, thus preventing undue heating at the joints.

The general arrangement of the circuit is shown in Fig. 1. The switchboard and the water rheostat are shown in Fig. 2 and the carbon holder in Fig. 3.

The selection of the proper carbon requires some care and while almost any kind may be used, such will not give the best results. The carbon is subjected to very hard usage, being alternately heated (frequently white hot) and cooled, this treatment having a tendency to cause it to crumble or flake and sometimes to crack in pieces. The flakes or pieces which happen to fall into the weld during the process are melted and mixed with the metal, thus producing a hard or high carbon steel very difficult to machine. Experience seems to indicate as best for heavy work, a hard, solid (not cored) carbon of one or one and one-half inches in diameter, six to twelve inches in length, and one that, as it wears away, leaves a round stub end and not a long pencil point. For lighter work, a carbon of smaller diameter will suffice.

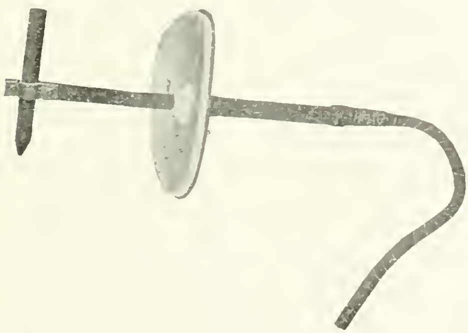


FIG. 3—CARBON TERMINAL

In the general repair of steel castings, iron rod of about three-eighths inch diameter is used for filling (Norway iron is preferable), although small pellets from scrap boiler plates or steel castings may also be used, the choice between the rod and the pellets depending, to a certain extent, upon whether the weld is small or large.

METHOD OF MAKING A WELD

As before mentioned, the positive terminal of the circuit may be clamped directly to the casting to be welded, as shown in Fig. 4, or it may simply be laid upon a metal table and the terminal clamped to the latter, as shown in Fig. 5. The positive terminal is thus connected instead of the negative terminal so as to direct the flow of current from the casting to the carbon electrode, and in this way prevent carbon, when the electrode is vaporized, from entering the

weld. The steel plates of the water rhostat are lowered into the barrels which have been previously filled with water, the circuit breaker and the switch closed, when the actual welding is ready to be undertaken.

The operator places himself directly in front of the casting, holding the negative terminal with its carbon electrode in one hand by means of the wood insulating handle, and having within reach of the other hand several pieces of iron rod. He then pulls the canvas cap well down over his head, as shown in Fig. 5, touches the carbon to the casting, thereby closing the circuit and thus producing an arc. As soon as the arc is sprung, the carbon is withdrawn to a distance of two inches or more (too short an arc will tend to produce a hard weld), and the arc allowed to play upon the casting until the metal commences to boil. It is advisable not to concentrate the arc on any one spot, but to give it a circular movement so as to heat the casting very thoroughly within the immediate vicinity of the proposed weld. This will tend to prevent too rapid cooling of the metal with its consequent chilling and hardening effect. The end of one of the iron rods is now placed directly in the midst of the boiling metal, where it gradually melts and mixes with it, the arc meanwhile being continued. As the rod melts away it is fed into the weld and this process is continued with one or more additional pieces of rod until the weld has been completed. The surface of the weld may be hammered as it cools off to produce a closer grain or to make it conform to some particular shape.

FIG. 4—WORKMAN REPAIRING A MOTOR FRAME

When pellets are used instead of the iron rod they are placed in the weld or cavity, a few at a time, and the arc applied, more pellets being added as the first batch is melted.

Should the part of the casting to be welded present a dirty appearance or contain slag, it should first be cleaned by means of a chisel or by the arc. In the latter case, this is accomplished by tilting the casting so as to allow the dirt or slag to drop off as fast as it melts when the arc is applied. After cleaning in this manner the casting is tilted back and the welding then proceeded with.

FIG. 5—WORKMAN REPAIRING A DEFECTIVE BEARING CAP

If possible, the weld should be made with one continuous application of the arc without allowing the casting to cool off. The reason for this is that oxide of iron (scale) will form with each cooling and if not removed will assist in producing a very hard weld, that is, one not easily machined. Where, however, it is not possible to make the weld with one application of the arc, the scale should be brushed off by means of a stiff wire brush. Hammering the weld after cooling will also very materially assist in this cleaning.

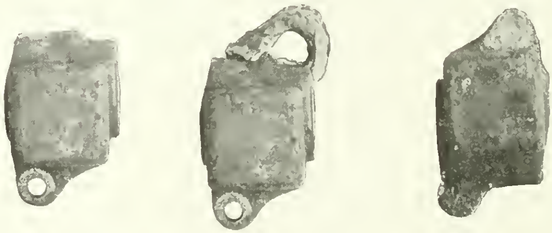
When instead of a cavity to be filled, it is necessary to build up a lug or to weld a piece to the casting, fire-clay or carbon blocks may be used for the purpose of confining the molten metal within certain desired limits or of having it assume a definite shape. The carbon blocks are generally worn-out dynamo and motor brushes and while they can sometimes be used without further dressing, being built up around the space to be filled by the metal, they frequently require cutting to shape with a knife. When fire-clay is used it is formed to shape by the hand.

A casting is shown in Fig. 6, which in the rough was apparently sound, but which on drilling and spot facing developed flaws in both lugs, one of these being spongy, the other breaking off entirely in the drilling. Fig. 7 illustrates very clearly the method of forming the fire-clay preparatory to building up a new lug, while Fig. 8 shows the casting after repairing and before redrilling.

A large motor frame casting is shown in Fig. 9. Upon removing the lower half of this casting from the sand, it was found that the strut which supports the axle lug had failed to pour, owing to the clogging of the mould with sand. A bar of wrought iron (1.5 inches by 4 inches by 14 inches) was accordingly fitted into position and welded to the casting, as shown, the whole operation being performed by one man in about two and one-half hours.

When the work is properly done, welds made by this method will give an average tensile strength equal to 70 or more percent of the original stock.

It would be exceedingly difficult, if not impossible, to set forth



FIGS. 6-7-8—DEFECTIVE BEARING CAP, METHOD OF PREPARING CLAY MOULD AND CAP AFTER WELDING AND BEFORE DRILLING

in exact terms the relations existing between current, size of weld, time required for weld, etc., on account of the different variables which enter in, but the following data, obtained in welding the spongy lug of the casting shown in Figs. 6, 7 and 8, is approximately correct and will enable a rough idea to be formed of the magnitude of the several items involved. It must, however, be borne in mind that this data represents average and not limiting values:

Line Volts	Amperes	Volts Across Rheostat	Volts Across Arc Including Carbon
126 (open circuit)	—	—	—
102	550	38	63
102	500	36	65
102	550	39	61
98	600	42	53
97	650	44	51
97	650	45	50
102	600	42	58

Time of weld=56 seconds. Hole filled=1¼ in. diameter by 2 in.—approximately. Size of carbon=1½ in. by 6 in.

Besides the welding of steel castings the Benardos process may be advantageously employed in the removal of surplus metal, including sink heads, in the boring of large holes in castings or plates, in the welding of flanges, elbows and couplings to pipes, and in a variety of other ways. It will be found, for example, that surplus metal and sink heads can in many cases be removed from castings in much less than the time required when a cold saw is used, the arc not only doing the work quicker, but there being practically no time lost in setting the casting in position—the same reasons apply to the boring of holes by the arc instead of by a drill.

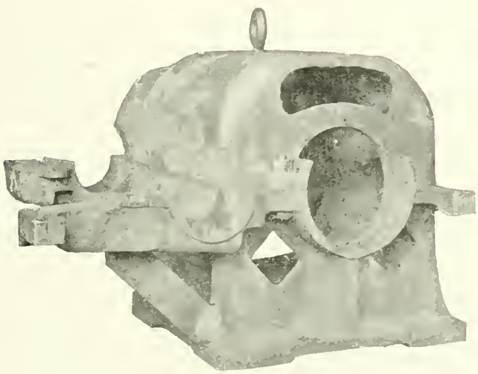


FIG. 9—MOTOR FRAME CASTING WITH NEW STRUT IN PLACE

In conclusion it may be stated that the Benardos process will give thoroughly satisfactory results commercially; it is one which can easily be learned by any workman of average ability, and only a few weeks' practice will be necessary in so doing. The welds first made will generally be harder to machine than the other portions of the casting, but where no machining is required, this will not prove detrimental; increasing familiarity with the process will, however, reduce the number of such hard welds to a minimum.

VOLTMETER COMPENSATION FOR DROP IN ALTERNATING-CURRENT FEEDER CIRCUITS

WILLIAM NESBIT

THE drop in alternating-current feeder circuits running out in various directions from a generating or sub-station varies in the different circuits, depending upon their length, the size of wire, the current being carried and the power-factor. For this reason it is necessary to impress different voltages on the various feeder circuits at the station in order to supply the proper voltage at the load. This is usually accomplished by the use of regulators in the feeder circuits at the station end, where the voltages may be independently regulated.

There are three methods in general use by which the voltage of the various feeders is known under all conditions of load and power-factor. These are as follows:

1—Two pressure wires are carried from the station voltmeter to the point at which the voltage is to be kept constant. The station voltmeter is then calibrated with these pressure wires in circuit so as to indicate the voltage at the point where these wires are connected to the feeder circuit. With this method the station voltmeter will indicate the voltage at the load under all conditions of load and power-factor provided there is no inductive effect upon the pressure wire caused by neighboring circuits. This method is costly, complicated and in most cases impractical.

2—Many station operators have gotten out a curve or a table for each feeder circuit, which curve or table indicates the voltage to be impressed on the circuit at the station end corresponding to various loads in amperes, in order that the desired voltage may be maintained constant at the load. This method will give correct results so long as the power-factor of the circuit remains the same as when the readings for the curve or table were taken. The principal objection to this method is that it is necessary to consult the curve or table each time before adjusting the voltage and then to find the new position on the voltmeter scale. This requires considerable time and a great deal of confusion in locating the new positions on the voltmeter scales. With this method the various feeder voltmeters will in general indicate different readings and these readings will change each time adjustments are made.

3—The third method consists of inserting into the circuit of the feeder voltmeter at the station a sufficient amount of resistance and reactance to modify the station voltmeter reading in such a way that it will indicate accurately the voltage at the load under all conditions of load and power-factor. With this method (provided the load voltage of all feeders is to be kept the same), all the feeder voltmeters in the station will indicate the same voltage although the actual voltage impressed on these feeder circuits may vary widely. If it is

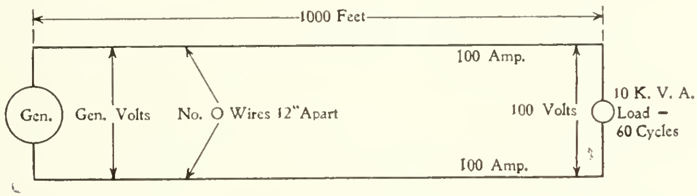


FIG. I

0.197x1x100=19.7 volts resistance drop;
0.209x1x100=20.9 volts resistance drop;
Total drop=21.5 volts or 21.5 percent.

desired to hold the load voltage constant at 110 volts on all the feeders, the operator adjusts the feeder regulators so that all the feeder voltmeters at the station indicate 110 volts, making the operation a very simple one. This method will be considered later.

CALCULATION FOR DROP IN VOLTAGE

Before taking up the matter of voltmeter compensation for line drop it may be well to review the familiar method of calculating and

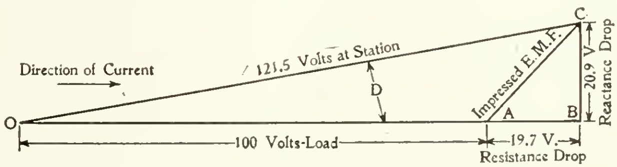


FIG. 2—REGULATION AT 100 PERCENT POWER-FACTOR LOAD

illustrating by vector diagrams the line drop in a given circuit at various power-factors.

In a paper by Mr. Ralph D. Mershon, consulting engineer entitled "Drop in Alternating-Current Lines,"* and treating of the various factors which affect the drop in single and polyphase circuits,

*See the JOURNAL for March, 1907, p. 137. See also article by Mr. Clarence P. Fowler, same issue, p. 152; also articles by Messrs. Chas. F. Scott and Clarence P. Fowler, April, 1907, p. 227.

are given a table of resistances and a chart for calculating the drop in alternating-current lines.

The combined drop due to ohmic and reactive resistance may be calculated as follows: Assume a single-phase circuit 1 000 feet long delivering ten k.v.a. at 100 volts and 60 cycles over two No. 0 wires 12 in. apart (Fig. 1). By consulting this table it will be seen that the resistance of 1 000 feet of line (2 000 feet of wire) is 0.197 ohms and this multiplied by the distance in thousand feet and by the amperes carried gives 19.7 volts as the resistance drop. This same table shows the reactance e.m.f. for No. 0 wire 12 in. apart to be 0.209 volts per 1 000 feet of circuit and this, multiplied by the distance in thousand feet and by the amperes gives 20.9 volts as the reactance drop. (These values have been assumed higher than usual, for the purpose of illustration.) By following out the instructions accompanying the chart, the total drop in the circuit due to resistance and reactance at 100 percent power-factor is 21.5 percent of the delivered voltage. This circuit is shown graphically in Fig. 2, where *AO* represents the voltage to be delivered at the load; *AB* the resistance volts drop in phase with the delivered e.m.f., *BC* the reactance volts lagging 90 percent behind the resistance volts, *AC* the impedance e.m.f. due to the combined ohmic and reactance e.m.f., *OC* the station voltage, and *D* the time angle of current lag at the station. Here the reactance e.m.f. being at right angles to the voltage of the load, has its minimum effect upon the regulation of the circuit, and the resistance e.m.f. has its maximum effect.

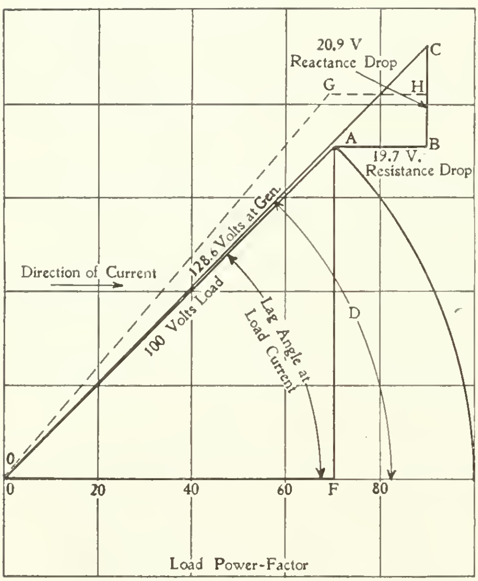


FIG. 3—REGULATION AT 70 PERCENT POWER-FACTOR LOAD

With a power-factor at the load of 70 percent this circuit would appear graphically as shown in Fig. 3. At this point the line drop

reaches approximately its maximum value for these values of reactance and resistance. Referring again to the chart for calculation of drop it will also be seen that point *C* falls upon the circle corresponding to a drop of 28.6 percent. Assuming an impossible condition of zero power-factor at the load, this circuit would appear as shown in Fig. 4. Here the resistance e.m.f. has its minimum effect upon the regulation of the circuit and the reactance e.m.f. has its maximum effect.

It is therefore seen that at high power-factors the resistance has a greater effect upon the regulation of the circuit and the reactance a lesser effect, than at very low power-factors, and vice versa. This is illustrated graphically by the curves in Fig. 5 which are based upon resistance volts of 9.85 percent and reactance volts of 10.45 percent. With these values at 70 percent power-factor the resistance and reactance have approximately equal effects upon the regulation of the circuit and at approximately this point the drop is greatest for equal values of resistance and reactance. The addition of the reactance and resistance drop curves gives the total drop curve.

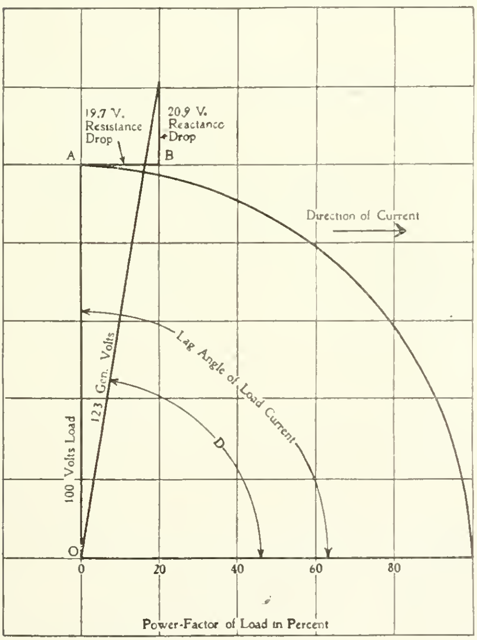


FIG. 4—REGULATION AT ZERO POWER-FACTOR LOAD

RESISTANCE COMPENSATION ONLY

It will be seen from the curves in Fig. 5 that it is important to compensate for both resistance and reactance drops when the power-factor is even only slightly under 100 percent. This is more clearly shown by the curves in Fig. 6, the upper curve showing the error for different power-factors with a constant k.v.a. load. In actual practice it would, of course, be very unusual to have a constant

k.v.a. output with such a wide range of power-factor as from 70 percent to 100 percent. The power-factor usually decreases as the load becomes less and by assuming that at 20 percent of normal load the power-factor is 80 percent, at 40 percent load it is 85 percent, and so on, and that a compensator for resistance drop only is used, then the lower curve in Fig. 6 is obtained, which shows that in this case there is an error of 2.5 percent at 90 percent power-factor. This error would be greater for greater loads at the same power-factor. It will therefore be seen that a considerable error may occur in the compensated voltmeter reading if resistance compensation only is used. If the proper reactance volts were introduced into this volt-

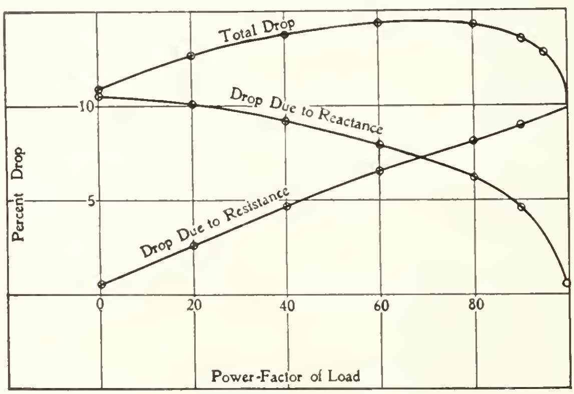


FIG. 5

Curves showing amount of resistance and reactance drop which combine to make the total drop for constant k. v. a. load at various power-factors. Resistance volts=9.85 percent; reactance volts=10.45 percent.

meter circuit and the ohmic adjustment set for 9.85 percent in place of 10.3 percent the errors in curves (Fig. 6) would entirely disappear.

TYPES OF COMPENSATORS

Mr. Ralph D. Mershon worked out, in the early days of alternating-current, a novel scheme of introducing into the station feeder voltmeter circuit a resistance drop and a reactance drop equal in percent to those of the line, thus producing a voltmeter circuit at the station which would coincide with the actual line circuit. This was slightly modified later in the form of a compensator shown diagramatically in Fig. 7. This diagram shows secondary windings

giving 24 resistance and 24 reactance volts compensation with five amperes in the circuit. In this diagram *C* is a potential transformer delivering at its secondary an e.m.f. proportional to and in step with the station e.m.f. *S* is a series transformer producing in its secondary circuit a current proportional to and in step with the main line current. *A* is a non-inductive resistance and *B* is a reactance coil.

A and *B* are connected in series and through them passes the current from the secondary of *S*. The e.m.f. between the terminals of *A* is, therefore, always in step with the back e.m.f. due to resist-

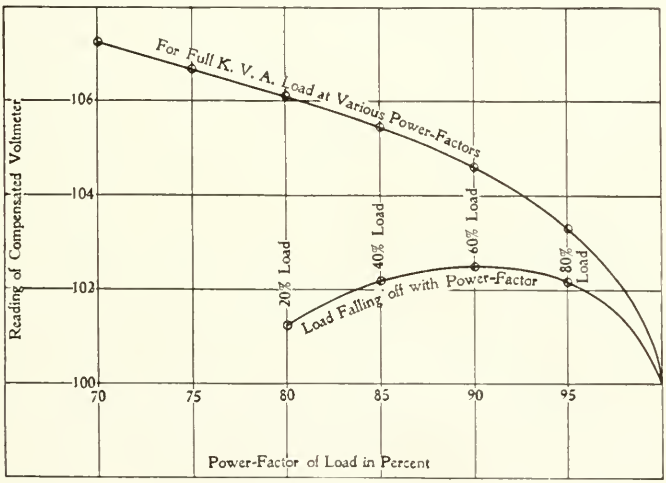


FIG. 6

Curves showing difference between total and resistance drop; i. e., the error in compensation when resistance compensation only is used and reactance compensation is disregarded, the actual resistance drop in this feeder being 9.85 percent and the reactance drop 10.45 percent at full-load current rating of compensator.

ance of line, while that between the terminals of *B* is in step with the back e.m.f. due to reactance of the line. *D* is a transformer connected in shunt to *A* and yielding at its secondary terminals an e.m.f. in step with and proportional to that across *A*. *B* has a secondary winding on it, so that it fulfills the double function of a reactance coil and a transformer, thus insulating the voltmeter circuit from the feeder.

B and *D* are each provided with ten leads which are carried out to switch contacts, permitting the resistance and reactance volts introduced into the voltmeter circuit to be varied at will. With the

proper amount of resistance and reactance volts introduced into the voltmeter circuit the desired result is obtained, since there is from *C* an e.m.f. proportional to and in step with that of the generator, and from *D* and *B*, e.m.f.'s in step with and proportional to the back e.m.f.'s due to resistance and reactance of the feeder circuit. The e.m.f.'s from *D* and *B* diminish the e.m.f. from *C* in exactly the same way and by exactly the same percentage as the back e.m.f.'s in the main line diminish the voltage from the station. The voltmeter will therefore always give an indication proportional to the voltage delivered to the load.

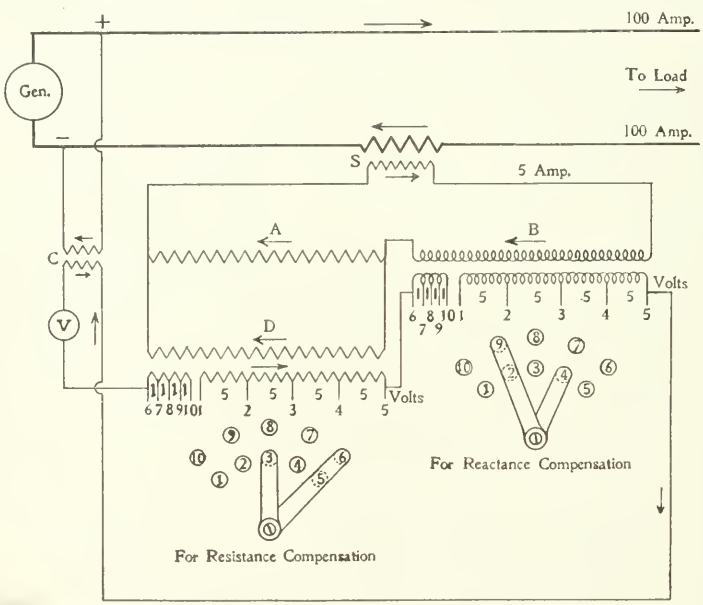


FIG. 7—CONNECTION DIAGRAM OF COMPENSATOR, 24 PERCENT COMPENSATION

The switch levers should be set so that at the rated current of the series transformers which is connected to the compensators the resistance and reactance in the voltmeter circuit will be equivalent to those of the line. Since both the resistance and reactance voltage of the compensator is exactly proportional to the current flowing (the same as in the line itself) the compensator, when set for the same resistance and reactance volts as that of the line at the rating of the compensator series transformer, will furnish the proper compensation under all conditions of load and power-factor.

TO ADJUST COMPENSATORS BY TRIAL

In order to calculate the amount of resistance and reactance of the circuit for which it is desired to adjust a compensator, it is necessary to know the size of the wire, the alternations, the distance between the compensator and center of distribution, etc. Accurate information of this kind is usually not readily obtainable. Furthermore, in nearly all cases current is taken from the feeder circuit at various points between the compensator and center of distribution, thus making it still more difficult to calculate accurately the resistance and reactance of circuits. Using these calculated values for setting compensators without a thorough knowledge of their workings often results in a loss of confidence in the compensator. Very confusing readings may be indicated on the compensating voltmeter when the power-factor changes if the compensator is not properly adjusted. It is strongly recommended that compensators be adjusted by trial. It is of little importance what the reactance and the resistance of the circuit at the current corresponding to the compensator

TABLE I—SWITCH SETTINGS FOR THE VARIOUS COMPENSATORS

Switch Points	Percent Compensation of Compensators Having a Maximum of 6 percent	12 percent	24 percent	36 percent
5- 6	.0	.0	0	12
5- 7	0.25	0.5	1	13
5- 8	0.50	1.0	2	14
5- 9	0.75	1.5	3	15
5-10	1.00	2.0	4	16
4- 6	1.25	2.5	5	17
4- 7	1 50	3.0	6	18
4- 8	1.75	3 5	7	19
4- 9	2 00	4.0	8	20
4-10	2 25	4.5	9	21
3- 6	2.50	5.0	10	22
3- 7	2.75	5.5	11	23
3- 8	3 00	6.0	12	24
3- 9	3 25	6.5	13	25
3-10	3.50	7.0	14	26
2- 6	3 75	7.5	15	27
2- 7	4.00	8.0	16	28
2- 8	4.25	8.5	17	29
2- 9	4.50	9.0	18	30
2-10	4.75	9.5	19	31
1- 6	5.00	10.0	20	32
1- 7	5.25	10.5	21	33
1- 8	5.50	11.0	22	34
1- 9	5.75	11.5	23	35
1-10	6.00	12.0	24	36

rating is, so long as the compensator has sufficient range for the circuit in question.

The curves of Fig. 8 show the indications of the compensating voltmeter for power-factors ranging between 70 percent and 100 percent with improper settings. Although in all cases considered in this diagram the compensator was set so as to cause the compensated voltmeter to read correctly, or 100 volts, at 100 percent power-factor, it gave incorrect readings at lower power-factors. The upper curve

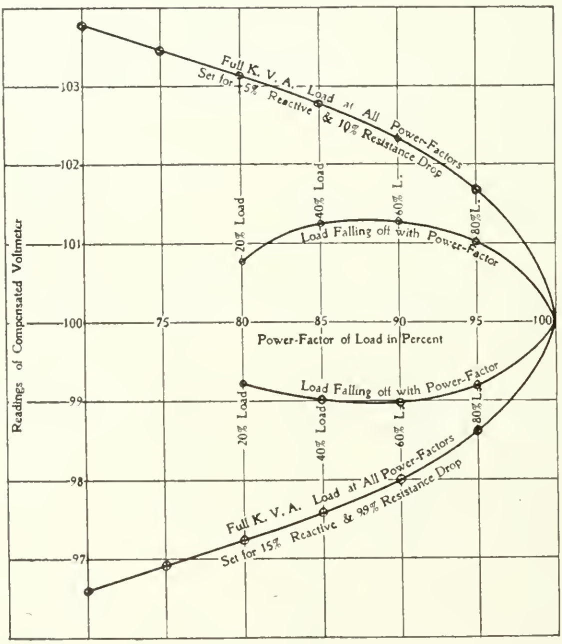


FIG. 8

Calculated readings of compensated voltmeter indicating the error due to change in load-factor with too little reactance compensation, and also with too great reactance compensation, the actual resistance drop in this feeder circuit being 9.85 percent and the reactance drop 10.45 percent at full-load current rating of compensator.

is plotted by assuming the compensator set for five percent reactance drop, or approximately half the true reactance drop in the line, thus causing the compensated voltmeter to indicate too high readings at less than 100 percent power-factor. The lower curve is plotted by assuming the compensator set for 15 percent reactance or 50 percent more than the proper amount, thus causing the compensated volt-

meter to indicate too low readings. The two smaller curves show the voltmeter indication assuming that the power-factor becomes less as the load decreases. Here it is assumed that the load is 20 percent of normal when the power-factor drops to 80 percent.

An illustration of the manner in which the curves in Fig. 8 were obtained is given by reference to Fig. 3, which shows a load power-factor of 70 percent. Here *OC* is the direction and amount of the voltage at the generator which is impressed on the secondary of the compensated voltmeter transformer; *CH* is the direction and amount of the reactance volts inserted in the compensator voltmeter circuit; *GH* is the direction and amount of the resistance volts inserted in the compensated voltmeter circuit; *OG,* therefore, represents the voltage impressed upon the terminals of the compensating voltmeter. The other points for these curves of Fig. 8 were obtained in a similar manner.

The following procedure is recommended for setting compensators by trial: Telephonic communication should be established between the station and the point at which the voltage is to be kept constant. When the load having the highest power-factor is being carried by the feeder (this will usually be at maximum load) the station e.m.f. should be adjusted until the proper voltage is being delivered to the load. At this time the switches on the resistance and reactance sides of the compensator should be set on points which will give the same reading on the compensated voltmeter as does the voltmeter at the load, the switches on the resistance and reactance sides being set at similarly numbered points. This setting would then be correct for all loads if the power-factor did not change. The power-factor will probably decrease as the load becomes less, and if at loads of lower power-factor the compensating voltmeter indicates a higher voltage than that at the load, not enough reactance is in the voltmeter circuit, and, hence, it will be necessary to increase the reactance until the two voltmeters read alike. If at loads of less power-factor the compensating voltmeter indicates a lower voltage than that at the load, too much reactance is in the voltmeter circuit, and it will be necessary to cut some of it out until the two voltmeters read alike.

The above adjustments should preferably be made at the maximum and minimum power-factors. If the first setting is made at a load at about 100 percent power-factor it will not be necessary to change the resistance adjustment at all, for the reason that any change which is made in the setting for reactance at the low power-

factors will have very little effect on the compensating voltmeter at high power-factors and *vice versa*. After adjusting the reactance at the lower power-factor the readings of the two voltmeters should be checked when the load having the maximum power-factor is again being carried by the feeder, and if the voltmeters do not read alike adjustment should be made on the resistance side only until they do read alike. This process may be repeated until the compensated voltmeter indicates correctly at all power-factors.

It is not necessary even to remember whether reactance should be added or taken out of the voltmeter circuit if the voltmeter reads too high or too low at low power-factor; all that is really necessary is to simply make all the adjustments on the resistance side for high power-factors and all the adjustments on the reactance side at low power-factors.

In adjusting a compensator time will be saved if at several points, say minimum and maximum loads and one intermediate point, readings be taken of the voltage, which must be impressed on the feeder circuit in order to secure normal voltage at the load. This may require a second voltmeter at the station end, but after these readings have been taken adjustments of the compnsator may be made without making a second set of observations at the load. Many stations have and use a curve or table indicating the voltage to be impressed on the various feeders for different loads which makes the adjustment of compensators a very simple matter.

SUMMARY

If compensators are properly adjusted for the circuits in which they are installed they will cause the station feeder voltmeters to indicate correctly the voltage at the load regardless of what the load or power-factor may be. If satisfactory results are not obtained it may be due to one or more of the following reasons:—

1—The connections may be such that the voltage generated in the compensator may be added to the voltage of the potential transformer, thus causing the compensated voltmeter to indicate a voltage higher than that at the station. This is corrected by simply reversing either the primary or secondary leads to the voltmeter potential transformer, thus causing the voltage generated in the compensator to oppose that of the secondary of the potential transformer. To determine if the connections are correct put the switch points on contacts *5-6* on both the resistance and reactance sides of the compensator. If the voltmeter indicates a lower voltage with the switches

on points *5-6* (compensator winding cut out) than it does with them on points *1-10* (compensator winding all cut in) the compensator voltage is not opposing that of the potential transformer and the leads to the potential transformer should be reversed.

2—The voltmeter at the load and the compensated voltmeter may not be calibrated alike. They should indicate alike with no load on the circuit and the switches on points *5-6*. If the load cannot be taken off the circuit to check them they may be inter-compared by means of a standard voltmeter.

3—The compensator may not have sufficient range of adjustment for the circuit in question. This may be quickly checked by putting the switches on points *1-10* on both the resistance and reactance sides. If now the compensated voltmeter indicates higher than the voltmeter at the load the compensator is too small for the circuit and one having a greater range will be required. On account of the large number of very small steps on compensators of this type (and the fact that the cost would not materially differ) it is advisable to install compensators having a range of compensation considerably greater than that which is actually required. In selecting compensators it must be remembered that the percent compensation marked upon them does not mean that they will furnish accurately the compensation for any and all circuits in which the line drop is the same as their markings.

The ratings of compensators are on the basis of five amperes flowing through them from the secondary of the line series transformers and a voltage at the load such as will give an indication of 100 volts on the compensated voltmeter. For instance, at normal current (five amperes) the 12 percent compensator will deliver to the voltmeter circuit a maximum of 12 volts resistance drop and 12 volts reactance drop. If the normal voltage of the compensated voltmeter is 100 then this will represent 12 percent resistance compensation and 12 percent reactance compensation, and this compensator would compensate for a line drop of approximately 12 percent at zero power-factor and also at 100 percent power-factor. At points between these limits it would compensate for greater line drops, and at 70 percent power-factor it would compensate for approximately 17 percent line drop. If, however, the voltage of the load is such as to require compensated voltmeter reading of say 120 volts in place of 100 volts, then the compensation would be $100 \div 120 \times 12$ percent or 10 percent for both resistance and reactance drop. At 120 volts the ability of the compensator to compensate for line drop would therefore be reduced considerably at all power-factors.

From the above it will be seen that a 12 percent compensator designed for use normally on a 100 volt circuit will not compensate for 12 percent line drop at 100 percent power-factor if the voltage of the compensated voltmeter is greater than 100 volts. Moreover, it will not compensate for 12 percent line drop even if the compensated voltmeter is operated at 100 volts, unless with this line drop the current transformer is delivering five amperes or more to the compensator.

A compensator should be selected to suit the resistance and reactance of the line. For instance, there might be a condition, especially in high frequency circuits, where the resistance drop is, say, 11 percent and the reactance drop 15 percent, in which a 12 percent compensator would give correct voltmeter reading at 100 percent power-factor for the reason that the reactance setting has little effect on the voltmeter reading at this power-factor, but it is evident that it could not be set properly for this circuit if the power-factor were much lower than 100 percent.

The simplest and easiest way of adjusting compensators is by trial and not by calculation.

In cases where power is taken from the feeders at different points, the center of distribution sometimes shifts, causing a slight error in the indication of the voltmeter. This shifting of load from one side to the other side of the point at which the voltage is to be kept constant is usually unimportant and, except in very rare cases, the indication of the compensated voltmeter may be used satisfactorily for adjusting the feeder e.m.f.

PROTECTIVE RELAYS

M. C. RYPINSKI

PROTECTIVE relays are used for the protection of circuits from abnormal and dangerous conditions such as overloads, short-circuits, reversal of current, etc. They act in conjunction with the automatic circuit breakers, operating when their predetermined setting has been reached, energizing the trip coils of the breakers and thus opening the circuit. Sometimes a main relay, due to inherent limitations, is not able to fulfill all of the necessary requirements. An "auxiliary" relay is then used in conjunction with the "main" relay and supplies the missing functions. Such missing functions may be, for example:

1—Lack of time element feature in the main relay.

2—Insufficient carrying capacity of the main relay contacts.

Protective relays may be subdivided according to their particular functions into the following classes:

Over-voltage
Overload
Overload and Reverse Current
Reverse Current
No Load
No-voltage
Reverse Phase.

These designations indicate the circuit conditions under which the various classes operate. For example, the over-voltage relay operates when the voltage rises above a predetermined amount; the reverse current relay operates upon reversal of current, etc.

Continuity of service is an essential consideration in all installations, and interruption of the service cannot ordinarily be tolerated unless the protection of the apparatus demands it. There are, however, certain abnormal conditions of current flow which may exist for a short time on a circuit without causing serious damage, such as swinging grounds, intermittent short-circuits, synchronizing cross-currents, etc. The simple relay

would in such cases act instantly and interrupt the service unnecessarily. There has, therefore, arisen the necessity for a relay having a retarded or time element action. For certain service it is sufficient that this retarded action have a definite predetermined value independent of the load condition. Such a relay is termed a "definite time" limit relay. For other service it is necessary that this time element vary inversely with the load, that is, with greater load the time element should be less and vice versa. Such a relay is termed an "inverse time" limit relay.

The definite time limit relay is usually employed where it is desired that the service be maintained at all hazards, no matter what the overload, so long as the overload condition does not persist beyond a definite length of time. This length of time is determined by the ability of the system to withstand overload conditions. Such a relay will also be of service in allowing a temporary short-circuit to clear itself where an instantaneous relay would act and interrupt the service.

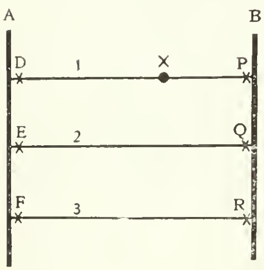


FIG. 1

The inverse time element gives a selective action varying inversely with the load; greater loads causing operation in quicker time and vice versa. The advantage of such a feature is that in a system protected by these relays, the ones which are nearer a point of disturbance and which, therefore, receive the greatest load will operate first, thus cutting out the affected part and clearing the system while confining the disturbance to a minimum area.

For example—Consider a system, as shown in Fig. 1, with three feeders—*1*, *2* and *3* connecting a set of power station bus-bars *A* with a set of substation bus-bars *B* and protected with automatic circuit breakers controlled by overload inverse time element relays at *D*, *E* and *F* and reverse current inverse time element relays at *P*, *Q* and *R*. Relays *D*, *E* and *F* will each be set for the same tripping value and *P*, *Q* and *R* will each likewise be adjusted for the same tripping value.

Assume that a short-circuit develops in *1* at point *X*. All three feeders will at once commence to supply current to the short-circuit from *A*. As *D* is nearest to the fault *X* and there-

fore in the circuit of the least line drop, it will receive more current than *E* and *F*. In virtue of the inverse time law, it will therefore operate first, thus cutting off the feeder *1* from *A*. Simultaneously *P* has been receiving current in the reverse direction through *1* from *2* and *3*, and has cut off feeder *1* from *B*. *Q* and *R* will not operate since the fault is isolated by the other relays and they are thus relieved of their overload.

In actual practice on alternating-current circuits, relays *P*, *Q* and *R* will operate on both overload and reversal of current, but are so designed that the operation on reverse current is at a much lower value than on an overload, so that, under the above conditions, as the reverse current through *P* is the sum of the normal fault current through *Q* and *R*, the tendency for *P* to operate before *Q* and *R* is still further increased.

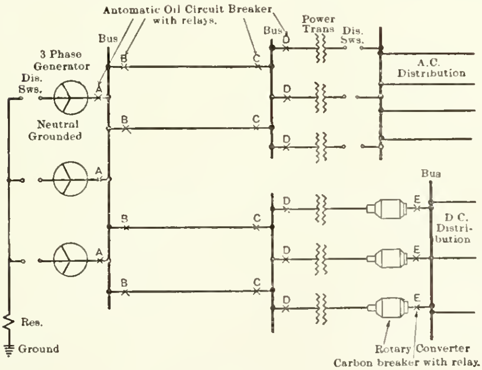


FIG. 2

Where only two feeders exist as, say, *1* and *2*, *P* and *Q* each receive the same amount of fault current and the selective action is not so great, but is amply sufficient to allow *P* to operate before *Q*. In a manner similar to the definite time element relay, the inverse time element relay will allow a temporary short-circuit or ground to clear itself, although this action is more limited than in the definite relay on account of the inverse time feature.

Either of these three actions may be incorporated with any of the classes outlined above, but actual service conditions have resulted in the development of the following standard types of relays. This list is quite complete for all ordinary conditions:—

STANDARD TYPES OF PROTECTIVE RELAYS

1—Direct-current over-voltage instantaneous relays.
2—Direct-current reverse current, instantaneous relays.
3—Direct-current reverse current inverse time element relays.
4—Alternating-current overload instantaneous relays.

5—Alternating-current overload inverse time element relays.
6—Alternating-current definite time element relays.
7—Alternating-current overload and reverse current inverse time element relays.

AUXILIARY RELAYS

8—Direct-current definite time limit relays.
9—Direct-current relay switches.
10—Direct-current bell relays.

The above relays in their simplest form consist of three elements: 1—The actuating mechanism energized by the line source to be protected; 2—a set of contacts operated thereby, and 3—the time element feature (where present).

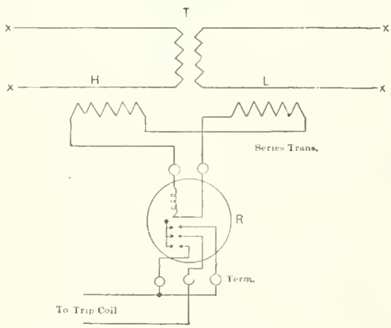


FIG. 3

Relays are ordinarily arranged so as to operate by closing their contacts, thereby energizing the shunt tripping coil of the circuit breaker mechanism from an independent source of current. This source is generally a direct-current exciter circuit or a storage battery.

When overload protection only is desired and an auxiliary source of power is not available, the overload relays are made with their contacts so arranged that they will be normally closed, these closed contacts being utilized to short-circuit a tripping coil which is energized from a series transformer connected in the circuit to be protected. When the relay operates, the short-circuit is removed, thus allowing current to pass through the tripping coil and operate the circuit-breaker.

PROTECTION OF ALTERNATING-CURRENT CIRCUITS

The application of relays to any given system depends almost entirely upon the local conditions of operation, varying somewhat with each installation. It is considered good practice to place on generator circuits either a reverse current relay with a time element feature or else to entirely eliminate automatic protection. For feeders at the power station end, over-

load inverse time limit relays are desirable. For feeders at the sub-station end overload and reverse current inverse time element relays are desirable. With rotary converters, overload inverse time limit relay in the high tension side of the power transformers will give protection for the alternating-current side. For the direct-current side a reverse current inverse time limit relay operating the direct-current circuit breakers will be required.

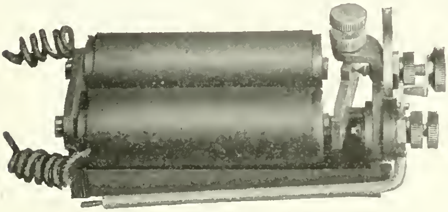


FIG. 4—DIRECT-CURRENT OVER-VOLTAGE RELAY

An example of the relaying required in a typical four-wire three-phase system is illustrated in Fig. 2. Three generators operating with their neutral points grounded through a resistance, feed a common bus-bar system, four sets of feeders, power transformers, rotaries, etc., for alternating-current and direct-current distribution of power. Automatic circuit breakers are inserted, operated by relays as follows:

At *A*—Alternating-current overload and reverse current inverse time element relays.

At *B*—Alternating-current overload inverse time element relays.

At *C*—Alternating-current overload and reverse current inverse time element relays.

At *D*—Alternating-current overload inverse time element relays.

At *E*—Direct-current reverse current inverse time element relays.

The relays at *A* are intended for reverse protection only and so have their overload adjustment set at the maximum value.

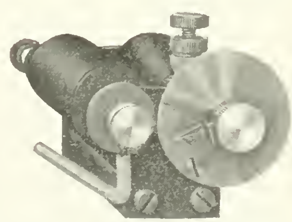


FIG. 5
End view of relay shown in Fig. 4

In transformer sub-stations, where a number of transformers are operated in parallel, a damaged transformer may be disconnected by means of the arrangement illustrated in Fig. 3. Here *T* represents any one of a bank of transformers connected in parallel, in the high and low tension sides of which are connected relay transformers *H* and *L*, arranged so that their sec-

ondaries are in series and oppose each other. These relay transformers are so selected as to tend to give the same secondary current under all normal conditions. In the event, however, of a short-circuit developing within the transformer the two sides will be unbalanced and a resultant current will flow of sufficient amount to operate the relay and disconnect both the high and low tension sides of the transformer.

Some circuit breakers are not adapted for relay tripping without modification, and some relays have not sufficient contact capacity to operate the trip coils of some of the breakers without the addition of auxiliary relay switches. The contact capacities of relays are limited by the capacity of the meter transformers from which they operate and from which sufficient power to give greater contact pressures and thereby greater carrying capacities cannot be secured without making the transformers unnecessarily large and costly.

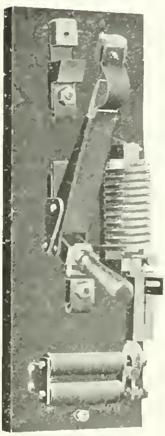


FIG. 6
Relay mounted on circuit breaker

DIRECT-CURRENT OVER-VOLTAGE RELAYS

Over-voltage relays are arranged to close a contact when the voltage of the circuit which they control exceeds a predetermined amount, thereby energizing the shunt trip coils of the circuit breaker and opening the circuit. Figs. 4 and 5 show side and end views of this type of relay. Its principal use is on battery charging panels but it may be used to protect any apparatus which would be liable to damage from excess voltage. In storage battery work it disconnects the battery from the circuit when fully charged as, under certain well defined conditions, the voltage of the battery is a measure of its charge. It must be remembered, however, in such applications that the voltage of a battery is dependent not only on its inherent characteristics, but also upon its charge and discharge history. Abnormal charging and discharging conditions operate to temporarily or permanently change the law of a battery's voltage curve and an over-voltage relay set for a given full charge condition may actually operate when the battery is not at full charge. The proper setting of a relay on such a circuit is a matter entirely to be determined by the operating conditions, full consideration

being given to the effect upon the full charge voltage of the charge and discharge factors.

In some cases these relays are mounted directly on the circuit breaker panels as when applied to overload and over-voltage type circuit breakers, as shown in Fig. 6.

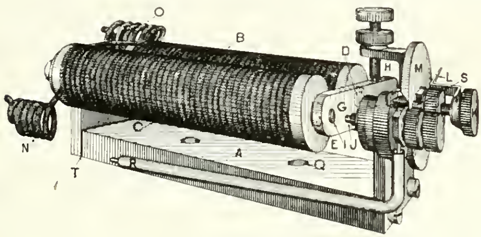


FIG. 7—DETAILS OF DIRECT-CURRENT OVER-VOLTAGE RELAY

A—Permanent magnet serving also as base of relay.
B, C—Coils wound on iron cores *D* and *E*.
G—Iron armature pivoted eccentrically at *H* and carrying a platinum-tipped contact *I*.
J—Stationary insulated tip against which *I* makes contact.
K—Adjustable screw which determines the travel of *I* away from *J*, carrying a pointer *L* which moves over a graduated stationary disk *M*, which is graduated in volts, the graduations varying with capacity of relay and covering a range of 20 percent above and below normal voltage. *L* is limited to a travel of 360 degrees by the pin *S*.

A sketch of one of these relays with the details lettered is given in Fig. 7. The coils *B* and *C* are so wound and connected that with the current flowing in the normal direction through the relay, *B* assists the magnet *A*, and *C* opposes it. The armature *G* is balanced and is under the influence of no force except that given by the fluxes of the magnet *A* and the coils *B* and *C*. *N* and *O*, the terminal leads of the coils *B* and *C*, are connected across the circuit in series with an external resistance (Fig. 8) of approximately 100 ohms per volt. A 100-volt relay, therefore, requires an external resistance of 10 000 ohms. One of the trip terminals is at *Q*, being grounded to the frame and thereby connected to *I*. The other trip terminal is the lead *R*, which is connected to the insulated contact *J*. With no current flowing in the relay the armature *G* is attracted at both ends by the cores *D* and *E*. *E* (owing to the eccentric pivoting of *G*) is able to exert the greatest leverage on *G*, and thus draws its adjacent end down which is the condition shown in Fig. 7. This opens up the contacts *I-J*. Upon applying voltage to the circuit of *B* and *C*, the opposition of *C* tends to neutralize the flux in the core of *E* while *B* assists to increase the flux in the core *D*. The re-

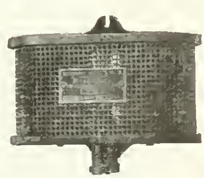


FIG. 8—EXTERNAL RESISTANCE

sultant effect is that the greater leverage of *E* on *G* is so reduced in effect by the decreased flux in *E* that *D* tends to overbalance it and at a value of the voltage determined by the setting of *K* does overbalance it, thereby moving *G* and closing the contacts *I* and *J*. The screw *K* acts to vary the effect of *D* on *G* by moving the latter nearer to *D* and farther away from *E* or vice versa.

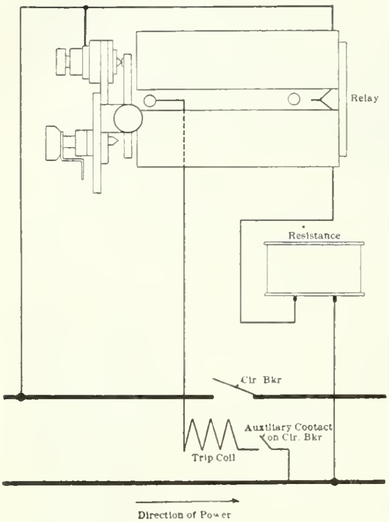


FIG. 9—CONNECTION DIAGRAM
Direct-current over-voltage relay

As the force of such an armature varies with its distance from the magnet pole piece, it will be readily seen how movement of *K* affects the action on *G*. The nearer *G* is to *D*, the lower the necessary operating voltage and vice versa. This type of relay is connected to the circuit according to the diagram shown in Fig. 9. The connections as applied on the panel base of an overload and over-voltage circuit breaker are shown in Fig. 10.

This type of relay will not operate on alternating current. It is polarized and the reversal of its connections to the circuit will cause it to operate on the reversal voltage. The contact *J* is adjusted with its contact point just over the coil side of the center line of the pivot *H*, in order that *G* may reset positively after making contact. With *J* behind the center line, the extra leverage of *E* and *G* begins to be neutralized by the distance of *G* from *E* as compared with that of *D* from *G* and the tendency is for the contacts to remain closed when the voltage decreases below the tripping value and the relay therefore, does not reset.

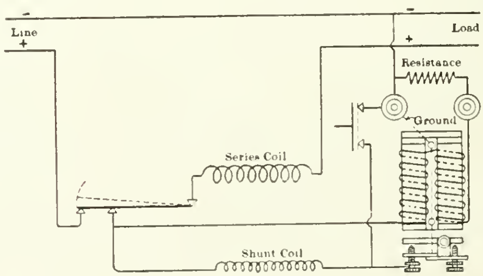


FIG. 10—CONNECTION DIAGRAM
Over-voltage relay used in conjunction with overload circuit breaker.

(To be continued.)

CIRCUIT-INTERRUPTING DEVICES—III

DISCONNECTING SWITCHES

WM. O. MILTON

THE disconnecting switch is a knife switch designed for high tension service. It differs from the ordinary low voltage knife switch in that special insulation is necessary and the switch is operated by means of an insulating stick. It is limited in operation also, as it is not designed for breaking power current but only for opening the circuit with charging current on the line.

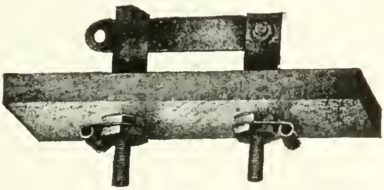


FIG. 1—DISCONNECTING SWITCH
Low voltage, rear connection

Switches for voltages not exceeding 3 500 volts (Fig. 1) are very much like the ordinary single pole knife switch, the difference being that the base must be of some good insulating material—usually marble or soapstone—and the blade instead of being supplied with a handle, has a hole in it for opening with a hook stick (Fig. 2). The distance from the nearest live metal part to the supporting screws or other ground must be much greater than on low voltage knife switches.

For higher voltages the current-carrying parts are mounted on insulators. The latter are ordinarily of porcelain, although other materials, such as glass and certain moulded compositions are sometimes used. There are two general types of switch, one on which ordinary line insulators are used, and the other a switch which has the current carrying parts mounted on corrugated pillars or bushings.

FIG. 2—HOOK STICK FOR OPERATING DISCONNECTING SWITCH

LINE INSULATOR TYPE

The line insulator type of switch (Fig. 3) consists of the current-carrying parts mounted on insulators which in turn are supported from a base usually of cast iron. The cap on top of the insulator as well as the pin on which the insulator is supported are attached by means of cement.

Mounting—Switches for 20 000 volts and less are usually mounted on one-piece insulators similar to that in Fig. 3. The distance between centers of jaws varies according to the voltage. For such switches a very suitable form of base is a bow casting as shown in the illustration.

Switches for higher voltages have insulators of larger dimensions made up of two or more separate parts cemented together. An insulator of this kind is shown in Fig. 4. Such insulators are supported from the base by pins either of wood or iron. When wooden pins are used for purpose of additional insulation, they should be "treated" to prevent deterioration and absorption of moisture.

FIG. 3
DISCONNECTING SWITCH
Line insulator type

Caps—The cap which is cemented to the top of the insulator is made of brass or copper, depending on the amount of current it must carry. In the case of the larger switches where the jaws are fastened to the cap by screws so that the cap itself does not carry current, it may be of cast iron.

Double Blade—Disconnecting switches for the higher voltages necessarily have a considerable insulation distance between contact jaws and therefore require rigid blades. One of the best methods of obtaining this rigidity is to have a double blade. Such switches ordinarily have a carrying capacity of at least 100 amperes on account of this form of construction.

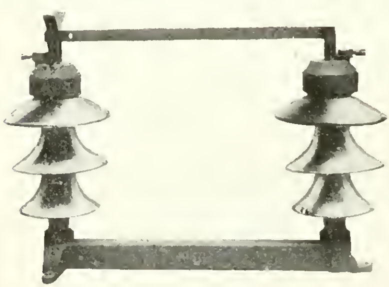


FIG. 4—DISCONNECTING SWITCH
Line insulator, high voltage type.

Finish—The line insulator type of switch is intended to be mounted apart from the switchboard and the object in view is to have a substantial construction with a durable finish rather than a highly polished piece of apparatus of the switchboard type.

SWITCHBOARD TYPE

The switchboard type of switch is shown in Fig. 5. It has insulators designed for cementing directly into the base which is usually of marble or soapstone. Thus, if the voltage is not too high, a

switch of this type may be mounted directly on the switchboard. For this reason it is often called the switchboard type to distinguish it from the line insulator type. This switch is more expensive than the other, both because the insulators are more costly and because the switch is usually highly finished. The capacity has thus far been limited to about 30 000 volts on account of the difficulty experienced in making satisfactory insulators of this type for higher voltages. The switch possesses the advantage, however, that it can be made with rear connections which is impossible, of course, with the line insulator type of switch. This switch is frequently built with both front and rear connections on one of the jaws, the object being to provide a connection for the lightning arrester.

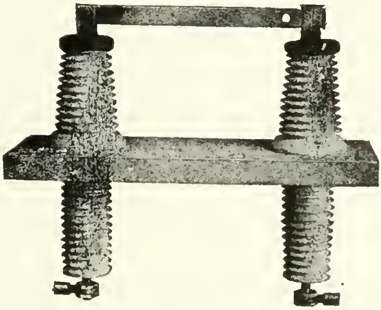


FIG. 5—DISCONNECTING SWITCH
Switchboard type, rear connection. For mounting directly on high voltage panel.

GENERAL FEATURES

Carrying Capacity—In the design of disconnecting switches the question of carrying capacity is not usually a serious one. In the first place the currents are low on account of the high voltages, 300 to 600 amperes being the sizes most frequently called for on heavy power circuits. Switches have been built for 2 000 amperes at 11 000 volts, but such heavy currents at high voltages are rare. The temperature rise will always be moderate if the same sections of metal and the same contact areas are used as on the standard knife switch, for the disconnecting switch has

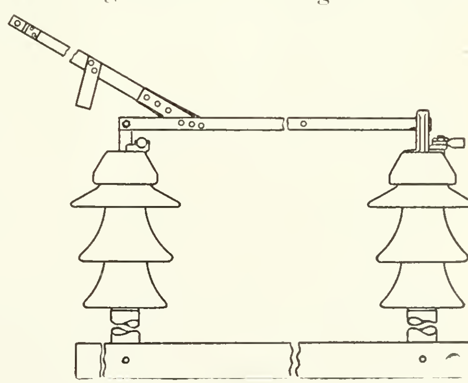


FIG. 6—DISCONNECTING SWITCH FOR HORIZONTAL MOUNTING
Arranged with operating lever so that the hook stick does not need to be brought near the base.

an advantage over the knife switch in that the radiating areas are larger.

Insulation—The questions of insulation distances and dielectric strength of porcelain are the chief considerations in the design of a disconnecting switch. Surface insulation on the higher voltages is taken care of by the design of the insulators. For the lower voltages, however, where the jaws are mounted directly on the base, it is very important, in order to prevent surface leakage, that there be sufficient surface distance between metal parts of opposite polarity and between live metal parts and ground. For ordinary materials such as marble or soapstone, the surface distances should not be much less than one inch for each 1 000 volts. Air distances need not ordinarily be much more than half the surface distances.

Mounting Apart From Switchboard—Disconnecting switches are most easily operated when mounted vertically against the wall. It is frequently necessary, however, on very high voltages to mount them horizontally among the roof trusses, to be operated from directly beneath. With any of the designs previously described, this would bring the operating stick directly past the base, giving a rather short distance over the surface of the stick from the blade to the base or ground. One way of overcoming this is to provide a projecting arm or lever. The hook on the stick can then be inserted in a hole in this lever at the end of the switch without coming in contact with the base as shown in Fig. 6.

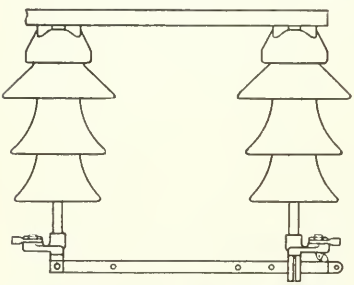


FIG. 7—DISCONNECTING SWITCH FOR HORIZONTAL MOUNTING
Inverted type with the current-carrying parts suspended from the insulators.

The most obvious design for meeting these requirements is to invert the switch and attach the current carrying parts to the pins projecting from the bottom of the insulators as illustrated in Fig. 7. With this design a catch is necessary to hold the blade closed.

Operating Stick—The operating stick is usually of treated wood, varying in length from two or three feet on the lower voltages, to ten feet or more for 60 000 volts. For voltages above 60 000 a hook stick long enough to be perfectly safe is rather unwieldy and some form of remote control is desirable.

TEST ON A 1 250 K.V.A. ALTERNATOR AT 80 PERCENT POWER-FACTOR

T. FRASER

Engineer, British Westinghouse Electric and Manufacturing Company, Ltd.

IT was desired recently to test a 1 250 k.v.a. turbo-alternator under full-load at 80 percent power-factor. The method used for obtaining the load for testing at this power-factor will perhaps be of interest. It is not claimed that this method is original, but, so far as the writer's knowledge goes, it is the first time it has been applied to the loading of turbo-alternators. At the place of test, the permanent loading arrangement for the turbo-alternators consists of a large iron water tank,* with plates arranged in the form of a triangle. The necessary gear is provided for changing the position of the plates to obtain different loads. This, of course, gives a non-inductive load.

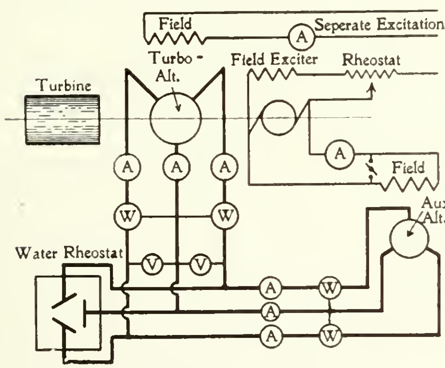


FIG. 1—CONNECTION DIAGRAM FOR TEST OF ALTERNATOR

Showing method of loading and of obtaining desired power-factor by floating auxiliary alternator on line.

To obtain 80 percent power factor, an auxiliary alternator was used, a duplicate of the one under test. The machine was run light as a synchronous motor from the alternator circuit, and its field was gradually weakened until the required power-factor was obtained. As it was not convenient to run up to speed and synchronize the auxiliary machine, it was started as an induction motor. From the diagram of connections shown in Fig. 1, it may be seen that the stators of both machines were electrically connected, the field of the generator separately excited, and the field of the motor short-circuited during starting. It was of course necessary to excite the generator field from an independently driven exciter, as otherwise no voltage could be obtained

*See article by N. J. Wilson on "Artificial Loading of Large High Voltage Generators," in the JOURNAL for November, 1907, p. 611.

until the machine reached a considerable speed. The turbine was started, and as soon as sufficient speed was obtained, (about 20 r.p.m.), the motor started up. When the motor reached full-speed, the field circuit was opened and the field excited.

Another method of starting was also tried. This was the same as the one already explained, with the exception of the field connections. Instead of being short-circuited, the field was connected directly across the armature of the shunt exciter, the exciter being coupled to the turbine. The field was built up gradually, as the turbine's speed increased, the two machines running in synchronism at all speeds. Absolutely no trouble was experienced with either method, and the power-factor could be adjusted to a nicety.

It will be seen from the diagram that the power-factor can be checked in three different ways:

First—From the ratio of wattmeter readings.

Second—From the ratio of k.v.a. and kw.

Third—From the wattless input to the auxiliary machine.

EXPERIENCE ON THE ROAD

POLYPHASE METER CONNECTIONS

M. B. CHASE

SOME time ago the writer was called to investigate an apparent discrepancy in measuring the output of a three-phase generator. It was said that the integrating wattmeter would not check with the indicating wattmeter, and that the error varied at different loads.

Upon arrival at the power plant, it was found that the switchboard had been designed by someone not familiar with the measuring of polyphase loads, who had installed a single-phase indicating meter in circuit with a polyphase meter and had given the operator instructions to multiply the reading of the indicating meter by three to obtain the correct amount of power being delivered by the generator. As the reading of a single-phase meter used in a three-phase circuit varies with the power-factor of the system, and also will read differently on different phases at any power-factor other than unity, it at once becomes apparent that the only remedy for

the trouble was to replace the single-phase meter with a polyphase meter. After this change was made, there was no further trouble in making the integrating meter check with the indicating meter.

Another case of error in measuring a polyphase load was found at a plant where a grain elevator company wished to determine the load upon a 75 hp three-phase motor with the idea of deciding the proper motor to purchase for similar work at another elevator. They had a portable polyphase indicating wattmeter and reported that the meter showed about 18 hp friction load and only about 23 hp with the elevator working to its full capacity. This showed about 5 hp used for the actual lifting of the grain while the foot-pounds of work done in one minute computed from the weight of the grain raised the height of the elevator showed at least 30 hp.

The writer requested the electrician who had conducted the test to connect the portable meter into the circuit as he had done on the previous test. This was done, care being taken to connect the meter exactly as shown on the diagram in the instruction book furnished with the meter. The motor was then started without load and the electrician proceeded to check the meter connection by opening first one potential circuit and then the other to note the direction of rotation for each side. As one side rotated in the reverse direction, he immediately proceeded to reverse the connections to get a forward rotation on this element. This, of course, should not have been done as the power-factor was below 50 percent due to the fact that the motor was running without load and under this condition one side of the polyphase meter should tend to reverse its direction of rotation. After restoring the meter connections to their original position the meter showed a load of about four hp running light and about 38 hp with the elevator running at its maximum, which figures checked very closely with the estimated load.

A CASE OF TOO HIGH POWER-FACTOR

C. W. KINNEY

An interesting case where a combination of circumstances conspired to conceal true conditions recently came up during the checking of a switchboard type integrating two-phase wattmeter against the voltmeter and ammeters on the panel.

The load consisted of several squirrel cage induction motors with shafting load only. The shafting load was very light, so that when the wattmeter, read for a period of fifteen minutes, indicated an average output equal to 95 percent of the kilovolt-amperes, it

was evident that something was wrong.

The workman claimed that he "connected the instrument according to the wiring diagram." It was impossible at the time to check the wiring, as there was no diagram at the plant. The writer discovered that the voltage leads of phase A were connected to terminals diagonally across the dial from the terminals to which the current leads of the same phase were connected. This suggested a possible explanation of the "good power-factor," as the lag of the current might be sufficient to bring it nearly in phase with the voltage when connected with the other leg of the circuit and still allow the meter to turn in the proper direction.

Phase A and phase B voltage leads were interchanged so that the voltage leads and the current leads for a given phase were connected to terminals on the same side of the vertical center line of the meter.

After the transfer the wattmeter was again checked against the ammeters and voltmeter and the power-factor was shown to be about 30 percent even with a slightly larger load on the motors. This power-factor seemed more consistent with the conditions.

A CASE OF SLOW SPEED

LEONARD WORK

Remedying a case of trouble carries with it as a sort of reward, a satisfaction not unlike that of winning a game. It is a struggle between man and machine. The more elusive and mysterious the difficulty, the more intense and interesting becomes the contest.

The following is a case in point, which no doubt has a familiar ring to those who have "been there," but shows how simple a trouble may be when found, but undiscovered appears extremely complicated. The writer was called to a private lighting plant where it was impossible to carry proper voltage at even half-load. The trouble was believed to be in the engine, but it was desired to make sure the generator itself was not at fault. A brief examination of the generator showed nothing more than that it was operating under considerably reduced speed, due to the driving power, a horizontal gas engine, which ran unsteadily and seemed to be laboring under diverse difficulties. The writer was invited to see if he could do anything with it, but after hearing that two different gas-engine "experts" had failed to produce any result, and that the owner him-

self had tried all remedies with no better success, it seemed a hopeless case.

However, here was an interesting game and so far the engine had defeated all comers. The invitation to try was accepted with many misgivings. A significant smile on the part of the owner was not reassuring. It appeared that the engine was either using an improper or contaminated mixture, or that the explosions were too late. The ignition was from a "hot tube."

When shut down examination was made for leaky valves by carefully listening while turning the engine slowly. The valves and also the compression were found to be all right. Next the hot tube was examined. As most of the flame which heated it burned above the tube, adjustments were made to lower the flame, which, in the main, was accomplished by turning on less gas, upon which the tube immediately became bright red—much hotter than formerly. The engine was then started. It came sharply up to speed. The entire load was thrown on. The lamps went to full brilliancy with the engine running easily and with plenty of power to spare. The owner, seeing the lights up to candle-power, came running in in great glee and declared he "never had such good light before."

The insufficiently heated tube had simply retarded the explosions and greatly diminished their effectiveness. This was the sole trouble. It was afterward learned that the engine builders had been appealed to. They suggested that, owing to the evident seriousness of the trouble, the engine be shipped to them for overhauling, which they would do for a considerable sum.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

1—OPERATION OF ROTARY CONVERTERS. What will happen to a rotary converter if the field circuit of the machine is opened when it is operating as a synchronous motor, the direct-current switches being open?

The machine will continue to operate at the same speed taking a large armature current, which is a lagging current in the generator. This current is usually several times the normal full-load current of the rotary converter.

2—What will happen under conditions which are similar except that the rotary converter is supplying current to a direct-current circuit, there being no other apparatus supplying current to this circuit?

The rotary converter will deliver current to the direct-current circuit taking from the alternating-current lines current both for magnetizing the rotary converter and for furnishing the power necessary for the direct-current circuit; the conditions are quite abnormal and damage will result at the commutator and by heating if continued for any length of time.

3—What will happen if, when a compound-wound rotary converter is supplying current to direct-current bus-bars in common with several other rotary converters, both the alternating-current switches and the shunt field circuit be opened?

Under this condition the rotary converter acts as a direct-current motor. When the shunt field is opened the armature will take a very large current and the speed will increase probably to the danger point. If there be a series winding the current flowing through it makes the rotary converter a series direct-current motor. The number of turns is usually too small, however, to prevent an abnormally high speed.

4—If a rotary converter operating in parallel with others has its alternating current switches opened what will happen?

The rotary converter will run as a direct-current motor receiving curren from the direct-current bus-bars. Its speed will depend upon the field excitation. If this be low the speed will increase; if it be high, it will decrease. If the rotary converter has a series winding the direct current flowing from the bus-bars to the armature will demagnetize the field thereby requiring an increase in speed to produce the proper e.m.f. in the rotary converter. Ordinarily the series field winding has a few turns only so that the relatively small current required for furnishing the power to rotate the idle armature of the rotary converter is too small to produce much effect upon the speed.

5—IN DRYING OUT A TRANSFORMER of the oil-insulated, air-cooled type, 23 000 to 2 300 volts, 150 kw-capacity, we propose to connect the 23 000-volt side to the 2 300-volt mains and put a rheostat in series with the secondaries. What would be the safe current in the secondaries without using oil?

In drying out a transformer of this size, it is generally not advisable to use more than twenty-five to fifty percent normal current. This, however, should not alone be used as a guide because the determining factor is the temperature obtained. This should be carefully watched by means of thermometers placed in contact with the coils while current is on.

A maximum temperature of eighty to ninety degrees C. is all that is advisable as such an observed temperature will usually be noted when there are actually points which would reach one hundred degrees. There is a decided variation in the characteristics of apparatus of various manufacture as to the readiness with which heat is conducted from the copper so that no definite rule can be laid down. Manufacturers of transformers generally issue instruction books giving details regarding the installation, care, and repairing of their apparatus. These can usually be obtained on application. If it is found that the information given therein does not give full details regarding the arrangement of apparatus and diagrams of connections for carrying on the work, it is advisable to write to the manufacturer regarding doubtful points as a seemingly unimportant matter of uncertainty will sometimes give rise to serious difficulty. Information regarding this subject has appeared in previous issues of the Journal. Note articles by Mr. J. S. Peck, in Feb., '04, issue, p. 52, and March, '04, issue, p. 61; by Mr. S. M. Kintner on "Methods of Treating Transformer Oil," in Oct., '06, issue, p. 583; by Mr. J. E. Sweeny, Aug., '06, issue, p. 478, and by Mr. C. E. Skinner, Feb., '05, issue, p. 96.

6—AUTO-TRANSFORMERS. Why does an auto-transformer have greater output than an ordinary transformer of equal size, and by what amount?

The auto-transformer is assumed to be one in which the winding is in two parts or coils which are connected in series. Terminals are brought out from each end of the winding and from the intermediate point. One circuit, say the primary, is connected to the intermediate and one of the end terminals, and the secondary is connected to the two-end terminals. The primary is therefore connected across one part of the winding. Suppose the secondary circuit were changed and were connected across the other part of the winding (instead of across the whole winding). Then it is easy to see that the transformer acts as an ordinary two-coil transformer and its output is determined by the voltage and the current capacity of its windings. Now suppose that the secondary circuit is connected in series with another circuit (having an e.m.f. of the same frequency and phase), then the secondary load may receive the same current as before but at a greater e.m.f. Again suppose that the e.m.f. which is connected in series with the secondary circuit be that of the primary circuit which supplies the primary winding of the transformer; then the secondary circuit can supply the same current as before at an e.m.f. equal to the sum of the original secondary and primary e.m.f.s. The connections are now obviously those of the auto-transformer. Hence, the auto-transformer may be regarded as an ordinary two-coil transformer in which the secondary coil is connected in series with the primary supply circuit. The secondary load may therefore receive the same current as it would if the transformer were a two-coil transformer, at an e.m.f. which is equal to the sum of the secondary coil e.m.f. and the primary circuit e.m.f. The ratio between the output of a transformer with independent circuits and the same transformer connected as an auto-transformer is therefore equal to the ratio between the secondary e.m.f. in the first case and the e.m.f. on the load in the second case, i. e., the sum of the e.m.f.'s on the primary and secondary windings. The following examples will illustrate. In each of the four cases the transformers are alike except in the secondary winding, and in each individual case the transformer itself is the same, whether connected to independent circuits or as an auto-transformer:

A—INDEPENDENT CIRCUITS	CASE 1	CASE 2	CASE 3	CASE 4
Primary e. m. f.....	100	100	100	100
Secondary e. m. f..	50	100	200	1 000
Secondary current.	100	50	25	5
Kw to sec. circuit..	5	5	5	5
B—AUTO-TRANSFORMER				
Primary e. m. f.....	100	100	100	100
Secondary circuit..	150	200	300	1 100
Secondary current	100	50	25	5
Kw to sec. circuit	15	10	7:5	5:5
Ratio of kw with ordinary connection to kw with auto-transformer connections	1:3	1:2	2:3	10:11

The primary and secondary functions are reversible; in any of the foregoing connections what has been considered as primary may be taken as secondary and vice versa.

To find the output of an auto-transformer, multiply its ordinary output (i. e. as a two-coil transformer) by the e.m.f. of the circuit which has the higher e.m.f. (whether this be the incoming or outgoing circuit) and divide by the difference between the e.m.f.'s of the incoming and outgoing circuits. Expressed in another way, multiply by the e.m.f. between the end terminals of the transformer and divide by the e.m.f. between the intermediate terminal and that end terminal to which only one of the external circuits is connected.

7—Induction Motors. What causes induction motors to hum?

It would be difficult to explain all the noises which are heard in induction motors when starting, running on light load, and on full load, etc. There are, however, two noises which may be distinguished and their causes explained. The first is distinctly a humming and is a magnetic effect resulting from the rapid alternations of current in the windings which gives rise to vibrations in the iron (when laminated). These vibrations cannot be entirely prevented, no matter how securely the laminations may be clamped together.

The other effect is commonly described as "whistling." The air currents passing through the ventilating ducts in the iron of the stator are cut by the slots in the rotor and a sound results. It is apparent that, if the design of a given motor is such that the number of slots in the rotor is approximately the same as the number in the stator or has the same prime factor, the sound resulting from the cutting of the air currents will be louder than if the number of slots were so porportioned that the air currents would be cut in rapid succession instead of simultaneously. Another way to eliminate whistling is to skew the rotor slots so that they are not quite parallel with those of the stator.

8—Induction Motor — Elementary Principles. Why has the armature winding of an induction motor no connection with the external circuit? What is the meaning of "slip"? Why is an external resistance used in the armature circuits and why is it not left permanently in the circuit?

It is well known that the currents in the stationary primary winding of a polyphase motor cause rotating magnetic poles—somewhat similar to the effect produced by the mechanical rotation of a permanent magnet. The secondary has currents induced in it which causes it to rotate, the tendency being to rotate at a definite and "synchronous" speed—the no-load speed is very nearly equal to the synchronous speed. When the motor is loaded the speed falls approximately in proportion to the load; this fall in speed is called the "slip." With a given load the slip may be increased by inserting resistance in the secondary circuit. Such a resistance enables the motor to start with less current from the line.

9—Fuses for Induction Motors. I have noticed that overload releases are used in some cases in connection with auto-starters for induction motors. Our motors have fuses. They are 75 hp capacity. I have been asked as to the advisability of adding overload releases and am of the opinion that they are unnecessary. What should I advise?

For induction motors up to 100 hp separate auto-starters are commonly used (not to be confused with auto-starter panels which are provided for use with high capacity motors and have overload release circuit breakers). Fuses are generally considered to be satisfactory for use with these smaller capacities of motors. One of the features of the auto-starters is that they are usually so arranged that the fuses are short-circuited during the process of starting. Heavy fuses could, of curse, be inserted in the starting circuit if found advisable in view of peculiarly heavy service. Hence fuses would be satisfactory for the conditions named under ordinary conditions. These motors will momentarily stand quite an overload, and it is seldom that conditions arise which require greater protection than is afforded by fuses.

10—In case the starting current of an induction motor is so large that it will blow the motor fuses if they are of a proper size for the full-load running current, what is the best arrangement to protect the motor?

Probably the best method is to use two sets of switches and fuses, one for starting and one for running. Heavy fuses may be used in the starting circuit after which the circuit may be switched over through line fuses which are of proper capacity for running conditions.

11—Are Auto-Starters always necessary for starting induction motors?

Constant speed motors having wound rotors are started and brought up to speed by applying one or more reduced e.m.f.'s to the primary winding in order to keep the current within a certain maximum. If collector rings are provided external resistance may be used in the rotor circuit. This increases the slip, increases the starting torque and limits the current. Auto-starters are usually used on motors having short-circuited type of rotor of five hp and larger. Single-phase induction motors have very little starting torque. A centrifugal clutch coupling or some similar device is often used, so that the motor can come up to speed before the load is thrown on.

12—Starting Motors for Rotaries. How are rotaries brought up to speed by induction motors?

If the induction motors had the same number of poles as the rotary, it would not bring the rotary quite up to synchronous speed. It is therefore necessary to give the starting motor a smaller number of poles than the rotary. For instance, if a rotary had ten poles, the induction motor for starting it should have eight poles. This would allow twenty percent slip in the induction motor, and still bring up the rotary to synchronous speed. See article on "How to Start Rotary Converters" in the July, 1905, issue of the Journal, p. 436.

13—Interpole Motors of the variable speed types (direct-current) sometimes have the pole face skewed between the two main poles, while the pole itself is parallel to the main poles. Why is this done?

By skewing the pole face of the commutating pole the advantage of a relatively wide pole face with decreased leakage is secured, i. e., the length of time that the coil, being commutated, is under the pole is from the time it enters the extreme tip of one side of the pole until it leaves the extreme tip of the other side. With a skewed pole face it is evident that this length of time is greater for a given width of pole face and the leakage to the main poles is no greater. This arrangement is especially advantageous where it is desired to make the length of the pole face less than the length of the armature iron.

14—Armature Winding. In your July, '04 issue a description is given of winding a direct-current armature. Suppose the commutator bars have no end tails that rise above the commutator proper, and that the ends of the coils are connected in the ends of the commutator bars; how can the ends be soldered in without melting out the solder in those ends previously soldered in? Any suggestions will be appreciated.

H. C. McG.

The main point in connection with the difficulty which you have explained seems to lie in the fact that where two leads are to be soldered in each bar, this soldering is ordinarily done on both leads at one time. The leads are held in the slots by first having a close fit and then being wedged in the slot by means of a tool known as a "drift"—a chisel whose blade has a dull or rather rounded edge and which is of such a thickness as to fit easily in the slot of the bar. By means of this drift the leads are "spread," one at a time, in the slot and in case the slot is so deep that the two leads do not entirely fill it, a short stub end of wire trimmed off from a coil already in place may be used to wedge into the slot on top of the two leads, thus completely filling the slot. It will be understood that if the slot is of proper width to give a close fit, it will require but little use of the drift to spread the leads sufficiently to hold them securely un-

til the soldering is done. The advantage of having the slot filled is that better electrical contact is obtained than would be possible were an amount of solder required to fill the space in the slot. It would probably be a difficult proposition to solder in leads as you suggest, i. e., one at a time, and do a satisfactory job. You are doubtless familiar with the method of soldering that is employed by large electrical manufacturers on some types of armatures in which the soldering of all the leads is done as a single process, after the leads are drifted into place, by dipping the commutator into a pot of molten solder of a sufficient depth to cover the commutator bars at the slots. This method is, of course, not practicable except where a large number of armatures are to be handled.

15—Operation of Dynamo. What is the effect of lifting one or two sets of brushes on a six-pole dynamo carrying a light load?

The effect would depend on the type of armature winding employed. If it is a wave winding, no harm would be done by lifting some of the brushes while carrying a light load. If it is a simple lap winding, no harm would be done unless the load actually carried was a greater proportion of the full-load than the proportion of the number of brushes remaining in service is to the total.

16—Variation in Air Gaps. What is the effect on a multipolar dynamo having one or two air gaps larger than the other?

The magnetic pull on the armature becomes unbalanced, increasing the journal friction and wear, unless it happens that there is an even number of excessive air gaps and these are diametrically opposite each other in pairs. If the armature is lap-wound, without any equalizer connections, differences in air gaps will cause local currents to flow in the winding and overheat it.

17—Cause of Ground in Conduit. I have considerable trouble with grounds in conduit wiring, supplying current to electric dumb waiters. The circuit is sometime opened while a machine is at full speed, thereby stopping it suddenly. Would this cause grounds?

If the connections are such that opening the supply circuit will not allow the shunt fields of the motors to discharge through a closed path, the field discharge may puncture the insulation and cause the grounding.

18—Alternator With Auxiliary Windings. In a revolving-armature alternator I noticed some auxiliary windings on the spokes of the spider; one-half of the winding was connected to the armature winding while the other led to a commutator to supply part of the field excitation. It was apparently a series transformer action to increase the field excitation at heavy loads. Will you explain this a little more and let me know if I am correct in my assumption? Where can I find a diagram of connections? I have failed to find this type of alternator mentioned in The Electric Journal.

The assumptions are correct. The primaries of the series transformers

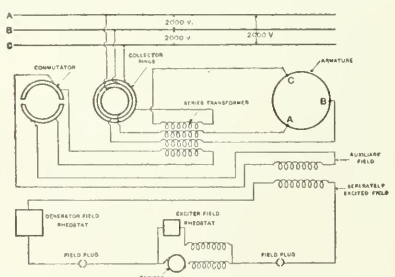


FIG. 1 — DIAGRAM OF CONNECTIONS FOR THREE-PHASE COMPOSITE WOUND ALTERNATOR

are connected in the armature circuit and the secondaries connected to a separate field winding through a rectifying commutator mounted on the armature shaft. The connections for this type of alternator for a three-phase machine are given in the accompanying diagram. This is not a very common form of machine. This particular type is rather obsolete,

THE
ELECTRIC JOURNAL

VOL. V. FEBRUARY, 1908 NO. 2

Electric Power in the Steel Industry

Electricity has been an important factor in the steel industry since 1892, when the Homestead Steel Works of the Carnegie Steel Company began the pioneer work in one of the first industrial applications of motors. During the earlier periods practically all of the raw material and finished stock in steel mills were handled by hand labor. The development of motor-driven driving tables, overhead traveling cranes and charging machines has done more to increase the economy and efficiency of the manufacturing methods used in the steel industry than any other one improvement.

By reviewing the existing conditions in one of the large steel plants of to-day, the numerous advantages of the electric drive are apparent. A central station of 4 400 kilowatts capacity furnishes 250-volt direct-current power for more than 1 000 motors of 25 000 horsepower total capacity. These motors are distributed over a radius of three-quarters of a mile from the station and operate tables, cranes, charging machines, screw-downs, saws, shears, fans, pumps and many other classes of machines. In a number of these applications it would not be practical to substitute steam or hydraulic power. The other advantages of using motor driven auxiliaries are that the efficiency of the system is good, especially as compared with steam engine direct drive; the distribution of power from a common center reduces the operating cost to a minimum and means a very economical ratio between the capacity of the source of power and of the driving units. It also insures greater reliability of constant service with uniform power. The use of large motors applied to rolls gives the same advantages and forms the final and greatest step in the question of power economy.

The article by Mr. Dick on "The Electric Drive of a Large Rolling Mill," in this issue of the JOURNAL, describes one of the most important achievements that have been accomplished in the development of motor applications to rolling mill work. It was only a few years ago that a general superintendent of one of the large

steel plants was advised that within a decade electric drive for reversing mills would be made feasible, practically and commercially. This statement was not given much credit, for in his mind the difficult problem presented by such an extremely heavy and fluctuating load and the requirements of rapid reversing appeared to have no solution from an electrical standpoint. The satisfactory results given by this thirty inch plate mill equipment, however, establishes the realization of this prediction.

The practical advantages offered by motor drive are—large starting torque; capability of withstanding heavy overloads; ease of control; uniform turning moment, and the absence of hammer-blow action during starting and stopping periods, this being due to a slight magnetic lag that has a damping effect. It is the commercial advantage, however, that receives most attention.

A close study of the operating economy as demonstrated by modern European practice has led to the universal adoption of motors in many of the new rolling mills, the power being supplied by generators direct-connected to gas engines using blast furnace gas. To illustrate to what extent this matter has attracted the attention of the steel works managers and engineers, it is sufficient to state that the equipments now installed and those on contract will aggregate over 75 000 kilowatts. Within the past two years a number of electrical equipments for driving rolls have been installed, including those for rail mills, plate mills, sheet mills and merchant mills.

The rail mill motors of the Edgar Thomson Steel Works were practically the first large roll motors to be put in operation and the very satisfactory service which they have given has been a direct answer to the hitherto open questions regarding motors for this kind of service. They operate twenty-four hours a day from Monday morning until Saturday night and have withstood extremely heavy overloads and the mechanical shocks incident to rolling, with practically a clear record regarding loss of time to the mill. After more than two years of service no deterioration whatever in these machines, including the bearings and the windings, can be detected.

The solution of the more difficult problems of reversing work will be of particular interest to the steel works managers who now have full assurance that the mill motor is a universal success. In this connection, the remodeling of existing plants is an important question. Mills operating several stands of rolls and auxiliary ma-

chines from a common line shaft could be arranged much more efficiently by using several driving units. It would make a good proposition to use motors for this work, furnishing power from the same economical source that is extensively used in Europe, consisting of a steam regenerator and low pressure turbo-generator which receive an intermittent steam supply from reversing or non-reversing mill engines.

The steel companies of this country are just beginning to take up the solution of this power question with regard to economy and the results obtained within the next few years will determine the extent to which large motor applications will be carried.

B. WILEY

Single-Phase Installations

The beginning of the new year sees the completion of three years of railway operation for the single-phase system. It seems to be a fitting time therefore to take a brief survey of what has been accomplished along these lines during this period. Mr. Blakemore's article, which appears in this issue of the JOURNAL, shows briefly and yet in a very striking manner the results which have been obtained.

The roads which have been equipped, or are under construction, amounting to 1 000 miles of line and calling for motive power aggregating 137 400 horsepower in capacity, and scattered over the entire country and differ widely in character. The possibilities which this system presents for meeting the varied requirements of railway operation are well illustrated by the wide difference in the character of equipments which have already been built and which range from the small motor-car using two fifty horsepower motors and intended for light interurban service operating over comparatively short distances up to the powerful locomotives of the New Haven and Grand Trunk systems.

Not only is the single-phase system competing with direct-current in the operation of interurban trolley roads, but a number of the steam railroads have also adopted this system for certain of their lines with most satisfactory results. The ability to maintain a high-speed passenger service with single-phase locomotives has been demonstrated on the New Haven Railroad. The abandonment of an infrequent train service on the Rochester division of the Erie Railroad and the substitution of single-phase motor cars operating

at frequent intervals has enabled this road to almost double its traffic. There appears to be no field in which the advantages to be derived from the adoption of the single-phase system are so obvious as in the electrification of the branch lines of the steam railroads. The Rochester line possesses further interest from the fact that the power for operating the road is transmitted from Niagara Falls, a distance of about 100 miles. The slow speed locomotives of the Grand Trunk Railway, Spokane & Inland Railway and the Shawinigan Railway are proving the suitability of this system for the movement of heavy freight.

Reviewing the situation as a whole it is gratifying to note the large amount of work under construction, thus indicating the confidence which is being manifested in the system, based upon the success attained on the roads already installed. One fact worthy of notice is that the lines which are already in operation are in most cases making further extensions. The Indianapolis & Cincinnati Traction Company, which was the first line to start commercial operation with single-phase equipments, has not only added several extensions to its system, but the operation of their initial installation showed such a great saving in operating cost over that which would have been possible with direct current, that they have adopted single-phase for their Shelbyville line, which is about twenty-five miles long, and which was operated previously with direct current. There is a marked tendency on the later roads to go to higher trolley voltages, which is evidently in recognition of the inherent safety of the catenary construction. There appears to be no reason why a 6 600-volt line, with the present design of catenary, should be any more dangerous for an interurban road than a 600-volt trolley of the ordinary construction. In general, the lengths of line being equipped are increasing, heavier cars and more powerful equipments are being used and higher schedule speeds are being reached.

There is another interesting fact connected with this development; namely, that, in spite of the large number of different types of single-phase motors which have been proposed and the various designs which are being put in service in Europe, all the single-phase motors now in operation in this country are of the straight series type with a compensated winding agreeing in general with the type designed by Mr. Lamme for the first roads to be put into operation.

MALCOLM MACLAREN

Modern Aids to Information

There is a tendency among young engineers who are entering the field of practical work to concentrate all their attention on the things immediately at hand. They take little pains to keep fresh what they may have studied at school, and they give little attention to anything technical aside from their daily work. One reason which is often assigned, for even neglecting the current electrical journals, is that all available energy and vitality are consumed in the daily routine or in the strenuous efforts to meet emergencies which are continually occurring in the erection and the operation of machinery. Those who succumb to such conditions, or to others which are much less weighty, fail to take a perspective view of their work and their development.

The following paragraph, from an admirable address by Mr. Charles Wallace Hunt upon "The Engineer," is worthy of careful reading.

"Engineering theory and practice are rapidly extending with the general advancement of our economic interests, and the engineer, whether he be a young graduate or otherwise, who does not make use of the modern aids to information, among which are to be counted scientific societies and a personal association with his brethren, with the innumerable hints and suggestions which come from these, will soon be found struggling with what seems to him adverse fate, but what, in reality, is inferior knowledge, behind hand knowledge, or, plainly speaking, ignorance, greater or less. The engineering world has passed by him, and he must view the working out of the law of the survival of the fittest with what grace he may."

THE ELECTRIC DRIVE OF A LARGE ROLLING MILL

W. A. DICK

THE increasing application of electric drive to industrial work is nowhere better shown than in the steel industry. Quick to see the advantages, the engineers of various steel companies have extended its use until now it is not uncommon to see a mill equipped throughout with electric drive.

The purpose of this article is to describe the apparatus used in a recent application of this drive to a large rolling mill at the plant of the Illinois Steel Company at South Chicago. This installation represents a novel and distinct innovation, both from the nature of the service requirements and from the size of the motors. They are by far the largest ever built in this country for such work.

THE MILL

The mill is a 30-inch universal reversible plate mill with two-high rolls, used for rolling plates and bars. It contains many new and interesting features which it is not the province of this paper to describe. The electric drive was designed and built by the Westinghouse Electric & Manufacturing Company. The estimates on the power required to operate the mill, including reversing, were furnished by the engineers of the steel company and were used as a basis in designing the electrical apparatus. They were very carefully worked out from data obtained from engine drives and from calculations. In general, the cycle of operations in rolling a typical piece includes thirteen passes through the rolls, the speed of the rolls for the initial pass being 40 r.p.m., with a gradual increase in speed for each succeeding pass up to the final pass, where a speed of 140 r.p.m. is required. The torque required of a driving motor was approximately 300 000 lbs., at one foot radius for the initial pass. The torque increases slightly for the next two passes and then gradually decreases, the final pass requiring about 60 000 lbs. The horse-power required is about 2 300 for the first pass and gradually increases up to the seventh pass, where it is approximately 3 500. From this point it gradually decreases until it is about 1 500. The average horsepower for the entire cycle is 1 300. A complete cycle, the time to roll a typical piece, is about eighty seconds.

THE APPARATUS

The apparatus consists of a motor for driving the rolls of a mill, a motor-generator or equalizer set with a large fly-wheel for supplying power to the motor and a system of control for operating the outfit. It is installed in a clean, well-lighted room separated from the mill proper. The location and arrangement of the several parts is shown in Fig. 1.

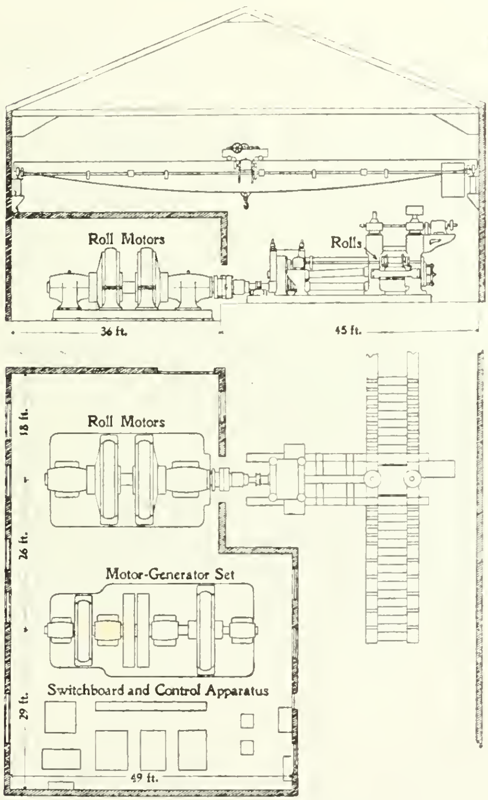


FIG. 1—PLAN AND ELEVATION SHOWING ARRANGEMENT OF APPARATUS

Owing to the necessity of very rapid reversals, the motor is built for direct-current, and is direct coupled to the rolls. Its field is separately excited and it is operated from the generator of the equalizer set and by a limited amount of field control. Its speed is varied at will over a wide range. It also operates as a generator in dynamic braking when stopping.

The equalizer set, which supplies the necessary power to the mill motor, consists of a direct-current generator, an alternating-current motor and a fly-wheel, as shown in Fig. 2.

The direct-current generator is separately excited and its voltage is variable. It also acts at times as a motor, receiving power from the motor of the rolls when the latter is braking. The alternating-current motor receives its power from a regular alternating-current supply system. The fly-wheel serves the purpose of a storage reservoir, receiving power from the alternating-current motor

at times of light load on the mill and from the mill motor when that is braking and giving out power at times of heavy load on the mill motor. The control regulates the alternating-current motor and controls the speed and direction of rotation of the mill motor.

Taking each of these different parts up in their order, a brief description will be given of its characteristics, design and method of operation.

THE MILL MOTOR

The mill motor has an intermittent rating of 10 000 hp at 575 volts. It consists of two units mounted on a common shaft with

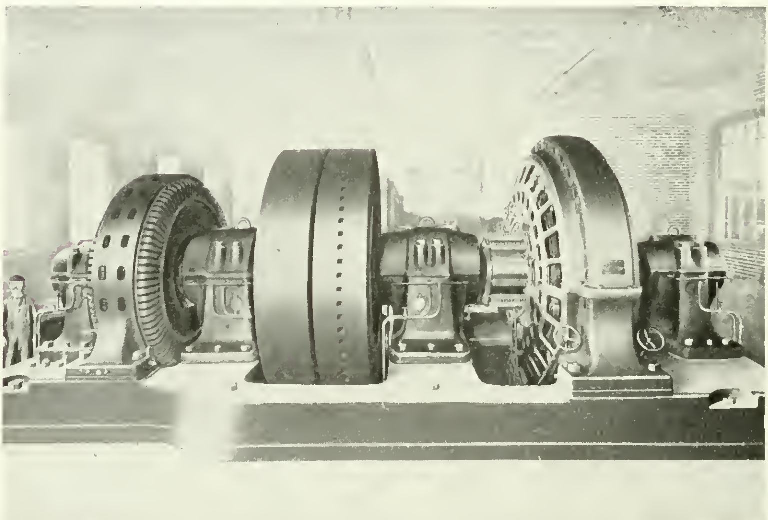


FIG. 2—THE EQUALIZER SET

common bearings and bed plate, as shown in Fig. 3. In order to secure a motor that could be reversed quickly without an excessive expenditure of power in accelerating, it was necessary to adopt a two-machine unit. With this arrangement a much smaller diameter of rotor can be used, and hence a reduced fly-wheel effect is secured.

The machines have twelve poles and a speed range in either direction of 0 to 150 r.p.m. As in the cycle of operation to be performed the torque decreases rapidly above two-thirds speed, the motors are wound to give 100 r.p.m. with full exciting field. The speeds above 100 r.p.m. are secured by shunt field control. The contract called for a reversal from full-speed in one direction to

full-speed in the other in three seconds. To obtain the rapid changes in field strength required to secure such rapid reversals, the field circuits are laminated, being built up of thin sheet steel punchings supported by a cast iron frame. To secure good commutation over the extreme ranges of torque and speed, recourse is had to a compensating winding through the field poles to neutralize the armature reaction, and to commutating poles to secure a fixed point of commutation. The punchings are made to include both the commutating poles and slots for the compensating winding. The field construction is illustrated in Fig. 4. The compensating and commutat-

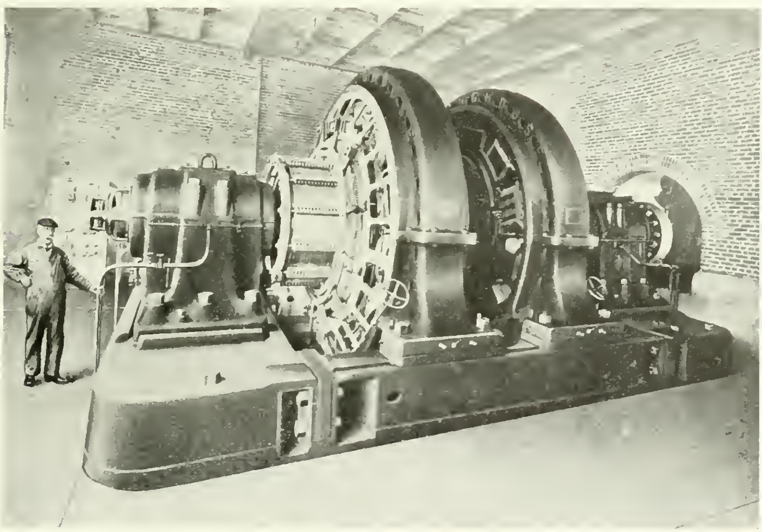


FIG. 3—MILL MOTOR DIRECT-CONNECTED TO ROLLS

ing pole winding is shown in Fig. 5. It is connected in series with the armature. The armatures are designed along well established lines, and are especially constructed to stand rapid and repeated reversals and shocks incident to mill work.

The shaft of the motor is hollow forged steel 28 inches in diameter in the armature spiders, 25 inches in diameter at the bearing on the coupling end, and 20 inches in diameter at the bearing on the outside end. The bearings are 62 and 54 inches long, respectively, have oil rings and forced oil lubrication and are water cooled. The bearing housing of the mill end of the motor is provided with a thrust collar and is especially strengthened so as to be able to withstand extraordinary shocks that would result should the

mill shaft break. The bed plate is of cast iron and of extra heavy section in order to secure the necessary rigidity.

THE EQUALIZER SET

The operation of such a mill motor as described above, if connected direct to a power house, would require amounts of power that would fluctuate over a wide range and involve

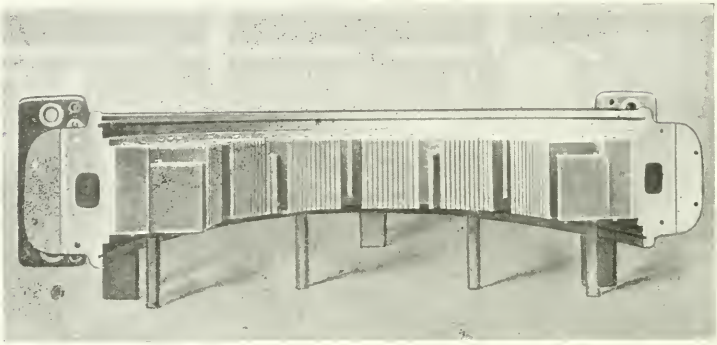


FIG. 4—VIEW OF ONE-HALF OF LAMINATED FIELD OF MOTOR BEFORE BEING WOUND

a large initial power house and transmitting installation. By the use, however, of a so-called equalizer set consisting of a generator to supply power to the mill motor, a fly-wheel and a motor to be operated from the line, a combination is obtained in which the load on the main power house is practically constant and equal to only the average taken by the mill motor. The motor driving such a set is usually an alternating-current motor taking its power from a regular power system. The design of this combination must be such that sufficient energy will be stored up in the fly-wheel during times of light load on the mill motor to supply that required at times of heavy load on the mill motor without the driving motor taking more than its normal load from the power house. To accomplish this the speed of the alternating-current driving motor is made to vary automatically, so as to allow energy to be taken from the fly-wheel or stored in it as required.

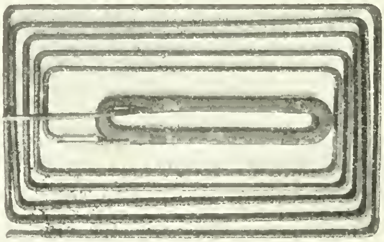


FIG. 5—COIL FOR COMPENSATING AND COMMUTATING POLE WINDING

An economical arrangement is thus obtained and one that makes very moderate demands on the main power house. Such is the scheme adopted in the present case, and the several parts of the equalizer set furnished will now be described.

The synchronous speed of the equalizer set is 375 r.p.m., and this can be reduced to as low as 300 r.p.m.

The set is of the four-bearing type, the fly-wheel being located in the middle with the generator at one end and the motor at the other. A good idea of the mechanical arrangement may be obtained

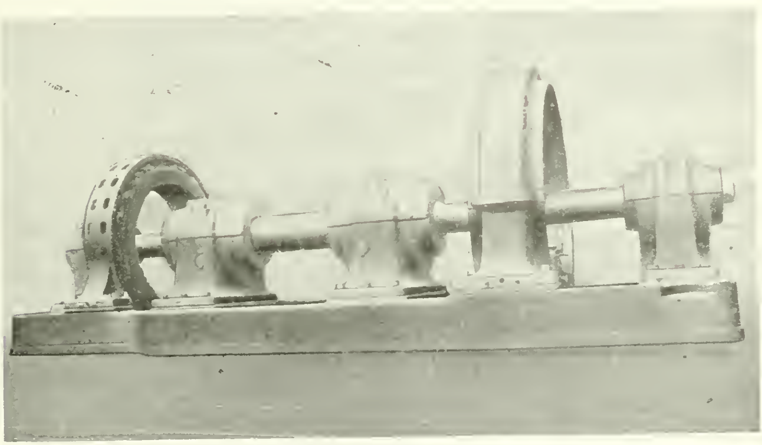


FIG. 6—EQUALIZER SET PARTIALLY ASSEMBLED SHOWING BED PLATE, SHAFT, BEARINGS AND MOTOR AND GENERATOR FRAMES

from Fig. 6, which shows the set partly assembled in the shop before shipment.

SHAFT, BEARINGS AND BED PLATE

The shaft is made in one piece approximately 34 feet long, 24 inches in diameter at the fly-wheel hub, 23 inches in diameter at the inside bearings and 15 inches in diameter at the outside bearings. The inside bearings are 54 inches long and the outside 40 inches. They have oil ring lubrication and are water cooled. The bed plate is of cast iron of box section, made in halves for ease in shipment. The cross-beams at the two ends are made separate and removable so that the machines can be moved out clear of their rotors in case repairs become necessary.

THE GENERATOR

The generator is wound for 600 volts at speeds of from 375 to 300 r.p.m., with a capacity suitable for operating the mill motor. In general design it is like the mill motors. The field circuit is laminated and the compensating and commutating pole wind-

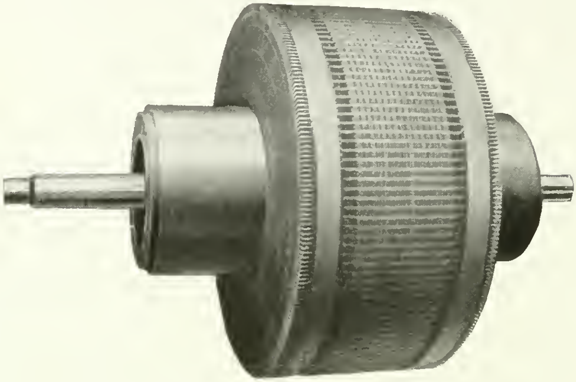


FIG. 7—ARMATURE OF DIRECT-CURRENT GENERATOR FOR EQUALIZER SET, WITH TWO COMMUTATORS

ings are the same in arrangement and construction. The fields of the generator are shunt wound and separately excited at 250 volts. The speed and direction of rotation of the mill motor is obtained by varying its shunt field excitation in direction and amount.

The armature of the generator differs from those of the motor in being constructed and wound for the higher speed and in having two commutators. Each commutator is connected directly to one of the two mill motors. Means are provided for securing the proper division of current between the two motors. A view of the armature is shown in Fig. 7. To secure a larger number of commutator bars between brush holder arms than would regularly be called for by the speed, connections are made from the commutator bars to intermediate points in the armature winding so that there is but one-half turn in the armature winding between adjacent commutator bars instead of a whole turn as ordinarily used. The scheme is illustrated in Fig. 8.

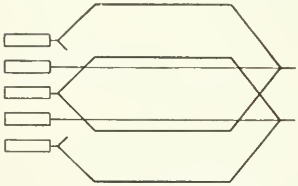


FIG. 8—SCHEME OF COIL WINDING

THE FLY-WHEEL

The fly-wheel of this set represents an interesting innovation in fly-wheel design. The requirements as to speed and weight were

such as to preclude the use of a cast steel ring with safety. Resort was had, therefore, to thin sheet steel and the wheel was built up of this material, in the shape of punchings, dove-tailed to a cast steel spider with overlapping joints and bolted together between two outside steel rings by numerous bolts. By using the sheet steel, the quality of the material in the wheel could be known definitely and a wheel of ample strength obtained.

For convenience in assembling and shipping, the wheel of this set was built in two halves. A view of one of these is shown in

FIG. 9—ONE OF THE TWO FLY-WHEELS FOR THE EQUALIZER SET

Fig. 9. The combined weight is 200 000 lbs. The diameter is 13 feet, two inches, giving a peripheral speed of 258 feet per second at 375 r.p.m. The radius of gyration is five feet, 2.5 inches, and the total fly-wheel effect 5 320 000 lbs. at one foot radius. The spider is cast steel, with arms of a section that will allow them to stretch sufficiently at normal speed so that the rim of the wheel will be self-supporting, the arms acting as drivers only.

THE ALTERNATING-CURRENT MOTOR

The induction motor is wound for 2 200 volts 3-phase and 25 cycles and has a continuous rating of 1 300 hp. It has eight poles, giving a synchronous speed of 375 r.p.m. and is provided with a wound secondary so that the slip may be varied by inserting resist-

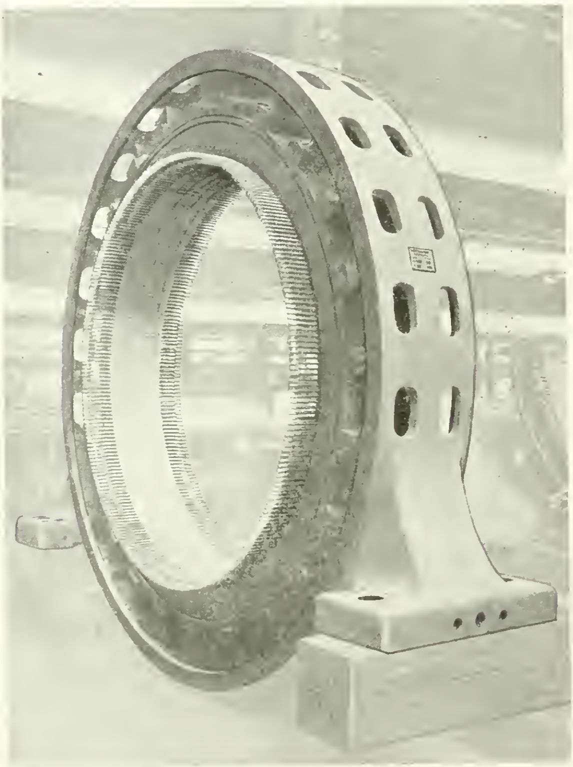


FIG. 10—PARTIALLY WOUND STATOR OF INDUCTION MOTOR FOR EQUALIZER SET

ance in series with it between the limits of 375 and 300 r.p.m. The stator is shown in Fig. 10 and the rotor in Fig. 11.

THE CONTROL

The purpose of the control apparatus is to maintain approximately a constant load on the induction motor of the equalizer set and to start and stop the mill motor and vary its speed and direction of rotation. A general view of the part used with the induction motor is shown in Fig. 12. In the foreground is the switchboard,

upon which are mounted switches and instruments for handling and measuring the incoming alternating-current power, for measuring the current and voltage taken by the mill motor and its speed and for controlling the speed of the induction motor. These consist of two direct-current ammeters, two direct-current voltmeters, a speed indicator, all for measuring the power taken by and showing the speed

FIG. 11—ROTOR OF INDUCTION MOTOR FOR EQUALIZER SET

of the mill motor; an alternating-current voltmeter, ammeter, indicating wattmeter, integrating wattmeter and a power-factor meter, for measuring the power taken from the line. The switching devices are—an automatic oil circuit breaker in the alternating-current circuit, a double-pole circuit breaker in the incoming direct-current circuit which excites the field, and several small switches for local circuits, two relays and a compensator used in connection with the induction motor.

In the operator's pulpit is placed an ammeter and a speed indi-

cator, so that the load taken by the mill and the running speed can always be seen. In the background of Fig. 12 are shown the switches and resistances used with the alternating-current motor, and at the right of the panel, the resistances used in the field circuits of the generator and motor.

At times when the fly-wheel is to deliver power, the slip of the induction motor is automatically increased by relays which insert resistances in the secondary circuit of the motor. When the power needed by the mill motor is less than the average taken from the transmission line, the relays automatically decrease the resistance in the secondary winding and thus decrease the slip and the motor

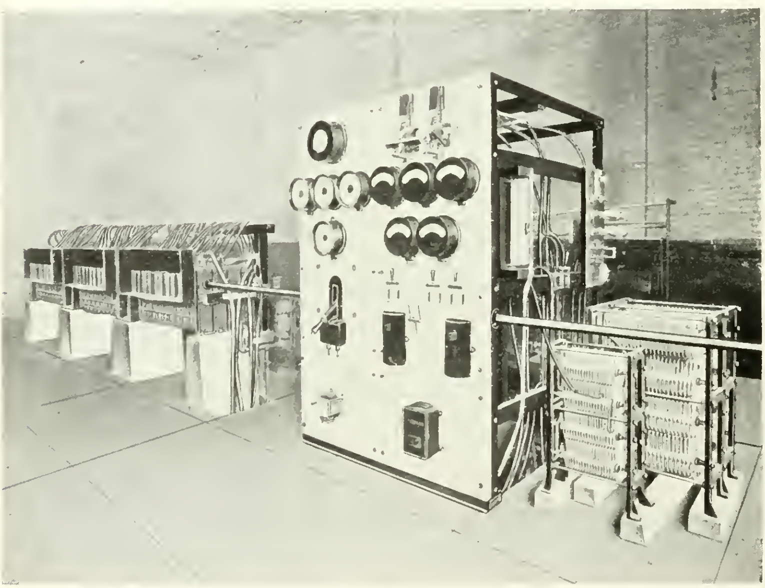


FIG. 12—CONTROL APPARATUS AND SWITCHBOARD

stores up the surplus energy in the fly-wheel. The varying of the resistance in the secondary circuit of this motor is accomplished by means of a series transformer in the primary circuit of the motor. The series transformer is connected to a compensator and through the compensator to two current relays. When the primary current falls below a certain value, both relay contacts are closed and cause switches, which short-circuit sections of the resistance, to be closed one after another in their proper order. When the current in the primary circuit of the motor reaches the normal value, one of the current relays lifts and prevents additional switches from closing.

This leaves the resistance stationary. Should the current in the primary of the motor exceed the normal value, the second current relay will lift and cause the switches to open one by one in their proper order, thus increasing the slip of the induction motor and reducing the primary current. Thirty electro-pneumatic switches are used to vary the resistances in the secondary of the induction motor. The air for operating them is furnished by a motor-driven air compressor. The valve magnets for these switches are controlled by the current relay and supplied with current from a set of storage batteries. These storage batteries are automatically charged by means of a battery relay operated by an air compressor motor. The battery current passes through a line relay which is controlled from a shunt transformer in the primary circuit of the induction motor. If the power supply is cut off, this line relay opens, and causes all of the resistance switches to be open when the controller is in position for again starting the induction motor. It can be started by simply closing the circuit breaker. The acceleration is automatic and controlled by the same current relays that vary the slip of the motor.

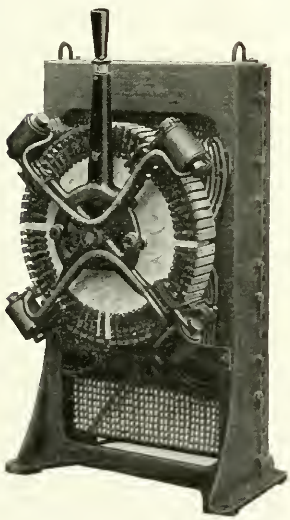


FIG. 13—CONTROLLER FOR OPERATING MILL MOTOR

A centrifugal switch is provided on the mill motor shaft to prevent the motor from running away. When the motor speed exceeds a safe limit, the switch closes a local circuit through a short-circuiting switch which operates on the underload trip coil of the direct-current circuit breaker and causes it to open. This reduces the generator field to zero and likewise the current in the armature circuit of the generator. Overload relays are provided which effect this same result should the armature current of the generator exceed a safe limit.

The speed and direction of rotation of the mill motor is controlled by controllers in the operator's pulpit. (See Fig. 13.) One varies the field of the generator in direction and amount, the other varies the strength of the motor fields for speeds above 100 r.p.m. These two controllers are interlocked in such a way that the motor fields cannot be weakened until full voltage has been applied to the generator field. Also, a magneto is driven from the motor

shaft. This magneto connects with a relay which, when closed, energizes the interlock coil. This interlock coil prevents the motor field from being weakened until the motor reaches the maximum speed at the maximum field strength.

SUMMARY

In studying an installation such as is described above, and comparing it with the steam engine drive which it supersedes, the question is apt to suggest itself, is not such a system rather complicated and expensive? It might appear so at first sight, and yet the answer to such an objection appears in the advantages of the electric drive over the other.

Briefly these may be stated as follows:

Increased output.

Simplicity and ease of control.

A noticeable reduction in the number of attendants required.

The concentration of the boiler plant in one place where steam is used, the central plant being much smaller than a number of isolated plants would be.

Where blast furnace gas is available, the ability to do away with the boiler plant entirely and use gas engines driving electric generators.

Decreased floor space.

Decreased power required through using equalizer sets.

Ability to measure power used accurately by recording instruments.

Wear and tear in the mill is lessened, as it is noticeable that the shocks due to reversals, etc., are much less severe with the electric drive.

All of which result in a material decrease in cost of production. The consensus of opinion is that the above solution of the problem of electric drive for reversing mills has passed the experimental stage, and that an extension of its use is sure to follow. The results already obtained have been very gratifying.

THE PROTECTION OF ELECTRIC CIRCUITS AND APPARATUS FROM LIGHTNING AND SIMILAR DISTURBANCES

R. P. JACKSON

GENERAL CONSIDERATIONS OF STATIC DISTURBANCES—CAUSES AND EFFECTS

An electric transmission line may be compared with a rubber tube filled with water. When the tube is subjected to an internal hydraulic pressure it enlarges a little and additional water is required to fill it. The hydraulic pressure and the additional flow of water caused by the stretching represent respectively the e.m.f. and the charging current of the electric line. If by a bursting of the tube, or by a compression due to an application of mechanical force, the pressure on the rubber tube is changed, the amount of stretch will change and a further flow of water one way or the other will result. If the change of pressure is very sudden, very considerable stresses may be brought to bear on the tube. In the same way abrupt changes of potential on a line cause changes in the charging current and may occasion severe stresses on the insulation.* Abrupt changes in the magnitude and distribution of electric charges, other than the comparatively gradual changes introduced directly by the generator, are designated by the name "static disturbances." These disturbances travel along line wires in the form of waves of electricity and cause stresses in the insulation of any apparatus they reach. These stresses are often greatest at the ends of lines, but may appear at any point on the circuit in which the disturbance occurs.

The chief cause of static waves produced by abrupt changes in the electro-static charge of a circuit, are lightning, the connecting of lines or apparatus to a live circuit, and grounds or short-circuits when of an abrupt nature. Lightning may cause destructive waves in any exposed circuit; the other causes are of importance only in comparatively high tension systems.

The stresses caused by static disturbances of sufficient severity result in either a spark to ground or a spark between the layers or the turns of a coil. This spark is momentary and usually small, but

*A fuller discussion of the cause and effects of static disturbances will be found in a paper entitled "Static Strains in High Tension Circuits and the Protection of Apparatus," by P. H. Thomas. Trans. of the A. I. E. E., Feb., 1902.

when the normal voltage of the circuit is acting in the coils at the time of the discharge, the momentary breakdown of the insulation may cause an arc to be started by the e.m.f. of the generator. It is this arc and not the original static spark that causes serious injury to the apparatus. In oil transformers, static sparks unassisted by the generator will do little harm unless often repeated; in air blast transformers even a static spark may cause a serious injury, since there is no oil to flow in and seal the puncture. Whether an arc will follow a static discharge or not depends on circumstances; other things being equal it is more likely to occur in apparatus of large capacity and it will not occur if the static spark passes at an instant of time when the e.m.f. of the generator is near zero.

Effects on Apparatus—The general effect, then, on apparatus is to puncture the insulation or cause a flash-over from one terminal to another or to ground. This puncture or flash-over is sometimes from the windings or leads to the ground represented by the case or iron cover; but it more commonly appears between turns of the windings—especially between adjacent layers—and produces partial short-circuits. This passing of a spark from one turn or layer of a winding to another or between layers does not necessarily indicate that the disturbance is between phases instead of to ground. The windings of a generator or transformer represent a considerable static capacity, and a charge coming from the line and entering such apparatus with great rapidity endeavors to spread itself over the windings more or less uniformly. Since the charge has but one point of entrance, that is at the lead, the result is that a spark passes from one layer or turn to the next. If the charge causing this spark could escape by passing freely to ground there would be no disturbance within the apparatus.

Effects on Line—The damage caused by lightning to a transmission line is sometimes one of the most annoying of its manifestations. While such effects, which usually appear in the form of broken insulators, are more severe and serious on steel tower lines than on wooden pole construction, yet neither is exempt.

Kinds of Service That Suffer Most—The breaking of insulators on transmission lines becomes serious only for voltages above 25 000 and apparently the difficulty increases with the voltage. Trouble with apparatus from lightning, however, has generally proven to be most acute with that for voltages from 4 000 to 15 000 and materially less on the higher voltages. Also, generators

for voltages between 4000 and 15000 are much more liable to suffer than transformers or switching apparatus. In general, the higher the voltage and capacity of transformers the more substantial they become and the more lightning will manifest itself in sparks and flashes over insulators, bushings, etc., without and within the power stations, rather than in damaging the apparatus.

Direct-current railway apparatus of recent construction is not nearly so vulnerable to damage from lightning as that of older manufacture; but wherever the overhead direct-current trolley is used, some trouble will probably always be experienced. Single-phase railway apparatus has thus far proved exceptionally free from troubles due to lightning. This is because the motors which are the vulnerable part of a car equipment, are on the low tension side of an auto-transformer and therefore entirely protected against lightning. The auto-transformer, being heavily insulated and a stationary piece of apparatus, is not nearly so likely to suffer as a direct-current motor.

APPARATUS AND OTHER DEVICES FOUND EFFECTIVE IN REDUCING LIGHTNING TROUBLES

Grounded Conductor on Transmission Lines—The most effective arrangement so far devised for reducing the breakage of line insulators by lightning is the overhead grounded conductor.* It is obvious that a transmission line covered by a grounded metallic shield could be reached by no external disturbance. Several metallic wires stretched over the transmission line wires and thoroughly grounded would give approximately the protection given by a metallic shield; even one or two such grounded conductors greatly reduces the electrical stresses to which the insulated line wires are subjected. Additional horns, or lightning rods, on each tower, reaching considerably above the highest insulator, have also been found to add to the protection. The grounded wire should be strong and well protected against corrosion, otherwise it may break and short-circuit the transmission lines, thus becoming a source of more trouble than it prevents. Such accidents have sometimes oc-

*A more extended discussion of the overhead grounded conductor is to be found in the following papers presented at the April, 1907, meeting of the A. I. E. E.: "Potential Stresses as Affected by Overhead Grounded Conductors," by R. P. Jackson; "Protection Against Lightning and the Multigap Lightning Arrester," by Messrs. Rushmore and Dubois; also a paper on "Lightning Rods and Grounded Cables as a Means of Protecting Transmission Lines Against Lightning," by Norman Rowe, presented at the May, 1907, meeting.

curred when very poor material was used. Further, this wire should be very thoroughly grounded; a ground should exist at every pole, though it is probably not so important that each of these grounds should have a very low resistance. An effective ground can be made for this purpose by burying a copper plate three or four feet in the ground, or by driving a 1.25 inch galvanized iron pipe to an equal depth. Either the plate or the rod should be connected to the overhead wire by a conductor preferably of the same cross section

FIG. 1—OVERHEAD GROUNDED CONDUCTORS ON TRANSMISSION LINES OF THE SOUTHERN POWER COMPANY

Two three-phase circuits; one grounded wire for each circuit.

as the wire itself. In addition to protecting the line against breakage of insulators, the grounded conductor carried above the transmission wires relieves the power-station apparatus, to some degree, of the stresses to which it would otherwise be subjected.

Station Apparatus—On reaching the power station, charges on transmission wires manifest themselves as high potential, high frequency waves. These charges may be diverted from the generators, transformers, etc., in two ways, viz., by providing vents, or safety

valves, for their escape to ground, and by interposing inductances in the path of the waves to partially reflect them back on the line or through the vents. The vent, or safety valve, is provided by installing some form of lightning arrester, while the inductance takes the form of choke coils.

The Ideal Lightning Arrester—A lightning arrester, to perform its function perfectly, should be a true safety valve. That is, it should take no current whatever at the ordinary operating potential; but at any undesirable potential above normal, the arrester should take current with sufficient freedom to limit the potential to some

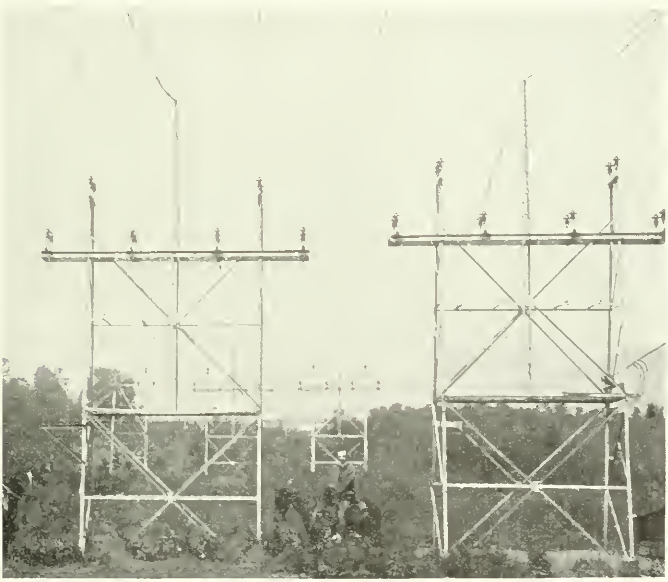


FIG. 2—OVERHEAD GROUNDED CONDUCTORS ON TRANSMISSION LINES OF THE MEXICAN LIGHT, HEAT AND POWER COMPANY

Four three-phase circuits; one grounded wire for each two circuits.

fixed and safe value. As soon as the excessive potential is removed, the arrester should cease to take current and should resume its original inactive condition.

The Choke Coil—A choke coil having considerable inductance acts as a reflector to high frequency waves, and serves to prevent the potential to which the leads of a generator or transformer coil are subjected from undergoing excessive or abrupt changes, or from differing greatly from the potential of the winding nearer the center of the coil. The inductance of the choke coil affords the protection,

and a coil that does not possess an appreciable amount of inductance is useless. Like other devices for protecting against lightning, the choke coil does not offer absolute protection, but serves, in a degree somewhat proportional to its inductance, to reduce the stresses to which power apparatus is subjected. From this it may be seen that a very large coil of many turns would give the largest degree of protection; but on the other hand, the size and inductance of choke coils must be limited, both on account of the drop which they cause in the operating voltage and on account of their cost. Consequently a reasonable adjustment has to be made between the amount of protection desired, and the drop and cost permissible.

At ordinary operating frequencies, the volts per turn in a choke coil is a very small value; consequently, though a surge may cause a spark to pass momentarily between turns, no arc will be maintained. This is necessarily not true of a transformer or generator coil; and for that reason, while increased insulation on the end turns is desirable, it cannot entirely take the place of substantial choke coils. While the normal voltage over a choke coil is very small, the difference of potential between its terminals during a high frequency wave, or surge, may become momentarily very great. In order to guard against a spark passing across the face of the coil at such a time, it is desirable to make coils for use on very high-voltage circuits oil insulated.

Insulation—While lightning disturbances are often far beyond what any insulation will withstand, it is still true that the best insulated apparatus suffers least; on the other hand, very poorly insulated apparatus is often so weak that protective apparatus, no matter how elaborate, will give but little relief from high potential. For this reason, it is very desirable that apparatus be built as rugged as possible, and that the factor of safety against insulation breakdown, both between turns and to ground, be liberal.

Protection Against Over-Potential at Normal Frequency—Under certain conditions, when a transformer with a high ratio of transformation is operating with the low tension side insulated from ground, the total low tension windings may receive a potential from the high-tension side. This event may happen if the insulation in the transformer between the high-tension and the low-tension windings breaks down; but the more probable cause is the accidental grounding of the high tension circuit, in which case the high and low tension windings of the transformer act as the plates of a con-

denser. Under normal conditions a three-phase system may be represented in relation to the potential to ground of all of its parts by a triangle rotating about its center, as shown in Fig. 3. Normally, all parts of the system may be considered as rotating in the same direction at the same rate and to have their centers of rotations in the figure on the zero line. There are consequently positive and negative charges with a consequent potential to ground as indicated by the shading of the lines of the triangles. So long as conditions are normal, the positive charge on one part of the winding is just equal to the negative on the other part and these charges follow each other in succession around the windings. Under these conditions, it does not matter whether the neutrals of the system be grounded or not; they will remain at zero potential.

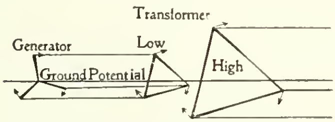


FIG. 3—RELATION OF POTENTIALS IN GENERATOR, TRANSFORMER AND LINES OF A NORMAL THREE-PHASE CIRCUIT

If, however, one side of the high-tension circuit becomes grounded, the condition shown in Fig. 4 takes place. In other words, the triangle of potentials for the high tension circuit rotates about its grounded corner. Obviously the transformer windings are alternately charged positively and negatively. To supply these alternate charges, an alternating current must flow through the grounded terminal. The low tension windings being closely adjacent to the high-tension windings, have a tendency to take a similar potential and the generator windings, being connected to the same, tend to follow. In reality the generator windings and iron form a condenser which is in series with another condenser formed by the high and low-tension windings of the step-up transformer. As may be seen if the ratio of transformation is high, it is possible that the potential of the low tension circuit may be represented by triangles rotating about centers some distance from their normal position. In fact, the whole low tension windings may be subject to stresses much greater than those which they normally develop within themselves.

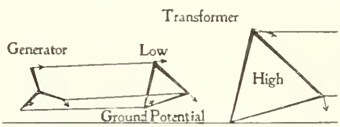


FIG. 4—CHANGES IN RELATION OF POTENTIALS IN SYSTEM REPRESENTED IN FIG. 3, AS A RESULT OF GROUNDING ONE SIDE OF HIGH TENSION WINDING

While the generating end of the line is as indicated above, the step-down transformer supplying power to a motor is also subject to

the disturbances. Ordinarily, however, there is no trouble, unless the transmission voltage is 20 000 or higher and the ratio of transformation five to one or greater. The best way to prevent this condition is to connect a neutral point of the low tension circuit to ground through a small resistance. If a neutral point is not available, it is sometimes desirable to produce an artificial neutral by the use of an auto-transformer.

Another simple remedy very commonly used, but not so entirely satisfactory, is to connect one leg of the low tension system to ground through a safety gap that will hold the normal operating potential but break over if any serious rise occurs. Only one such gap should be connected to a given circuit, or a short-circuit may be produced by the simultaneous breaking down of two such gaps connected to parts of the circuit having a difference of operating e.m.f.

Cable Protection—Underground metallic sheathed cable circuits ordinarily have inductances considerably lower than those of the same length of overhead transmission line, but possess large electrostatic capacity from conductors to ground and between conductors. Because of this excessive capacity, surges in underground cables are liable to carry a larger amount of energy than is possible on an overhead line of otherwise similar characteristics. On reaching the cable heads, i. e., the points where the cable joins the overhead lines, the larger cable charges are unable to escape readily to the overhead wires which have much lower electro-static capacity and are partially reflected at the points of junction with consequent rises of potential at these points; cable heads are therefore subject to very severe electrical stresses. At all such points discharge gaps may be placed and so arranged as to give a moderately free discharge. A discharge resistance low enough to give anything in the nature of a short-circuit is of course undesirable, but, on the other hand, a discharge very much retarded by ohmic resistance is liable to prove ineffective in relieving the high potential.

By keeping the potential of the system symmetrical in relation to the ground, it is also often possible to prevent, to a large extent, these surges and oscillations in a cable circuit. The most effective method for obtaining a symmetrical potential is to ground the neutral of the system through a small resistance.

(*To be continued*)

CIRCUIT-INTERRUPTING DEVICES—IV

CIRCUIT BREAKERS—GENERAL

F. W. HARRIS

A CIRCUIT BREAKER is a device for opening an electric circuit under normal or abnormal conditions of current or voltage. It is generally automatic, its action depending on the occurrence of some condition previously determined upon. The majority of circuit breakers depend either upon oil for quenching the arc or on carbon contacts for rendering it harmless. Various special forms such as circuit breakers with magnetic blowouts or fused circuit breakers with expulsion tubes have been devised, but in general, carbon-break and oil circuit breakers cover the field. For the purpose of this series, circuit breakers are classified under three headings,—carbon, oil, and special.

As nearly all circuit breakers may be provided with a trip coil, so arranged that when energized it will cause the circuit breaker to open, it may therefore be said, broadly, that any condition, which admits of being measured, may be used as a means for closing small contacts, and thus opening the circuit breaker. This method of providing a tripping coil and energizing it through auxiliary contacts makes possible the use of relays with all their adaptations and modifications.

Circuit breakers are commonly classified as overload;—opening when current exceeds certain value; underload, opening when current falls to a certain value; and over and under-voltage, similarly defined. Another type commonly used is the reverse-current whose operation is governed by the direction of current. Combinations of several of these functions in one device are also common.

Circuit breakers are generally arranged to be tripped manually in addition to such automatic trips as may be provided. By removing the automatic features circuit breakers can be made non-automatic and the hand trip used to open them. Non-automatic circuit breakers are often desirable where switches would not have sufficient breaking capacity.

METHODS OF OPERATION

Circuit breakers may be manually, electrically or pneumatically operated, the names indicating the means employed for closing the contacts.

Hand operation—Hand-operated circuit breakers which form the largest class, may be closed directly, or by distant control through a series of bell cranks and levers. When the operator must necessarily be at such a distance, or in such relation to the circuit breakers that he can not operate them directly by hand or by a system of levers, it becomes necessary to substitute some source of power to actually close the mechanisms, this power in turn being controlled by the operator.

Electrical operation—Electrical operation is most convenient

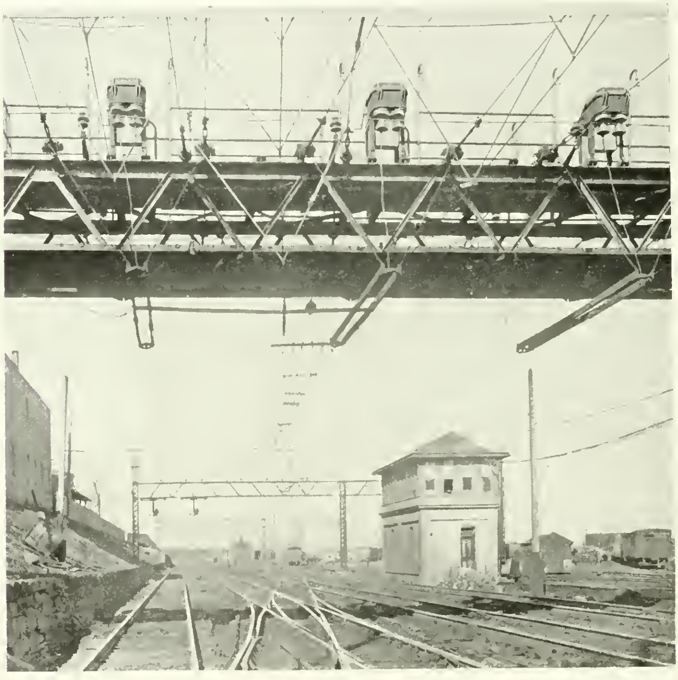


FIG. 1—ALTERNATING-CURRENT RAILWAY CIRCUIT BREAKERS ON BRIDGE

as the mechanism is operated by closing the circuits of the coils or motors which operate the mechanism. Practice and opinion differ somewhat as to the relative merits of coils or motors for this purpose. The principal argument for motors seems to be the unlimited power available, motors of any capacity being practicable. No difficulty, however, has been experienced in designing coils for any capacity of circuit breaker thus far required. The power for energizing such coils is generally from a direct-circuit source, as thus far there has been very little demand for electrical operation

on alternating current. Electrically-operated circuit breakers are usually installed in generating stations where direct current is necessary for excitation and it is preferable to operate the circuit breakers with power from this source rather than to depend upon the main circuit which is liable to be affected by short-circuits. For the same reason, in switching stations or transformer substations, it is generally considered advisable to install a small storage battery or a motor generator set.

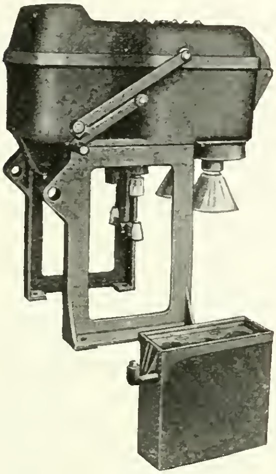


FIG. 2—OUTDOOR CIRCUIT BREAKER, WITH TANK REMOVED

An example of an installation where alternating-current operation is desirable is furnished in the case of an alternating-current trunk line electrification where direct-current is not available. Here the electrical circuits are controlled from signal towers by means of circuit breakers located on bridges as shown in Fig. 1. As there must be a large number of towers and circuit breakers, battery operation would be expensive and complicated, and, therefore, these circuit breakers are arranged to be actuated entirely by alternating current. Both the main and auxiliary coils of circuit breakers of this type (Figs. 2 and 3) are operated with alternating current. One advantage of alternating-current coils lies in the fact that, as the magnetic circuit closes, the current in the coil decreases, thus resulting in a practically constant pull and a very small current when the mechanism is finally closed. The difficulties of design and operation of alternating-current coils lie chiefly in their inefficiency and expensive construction. The reasons for preferring coil operation to motor operation are these:—

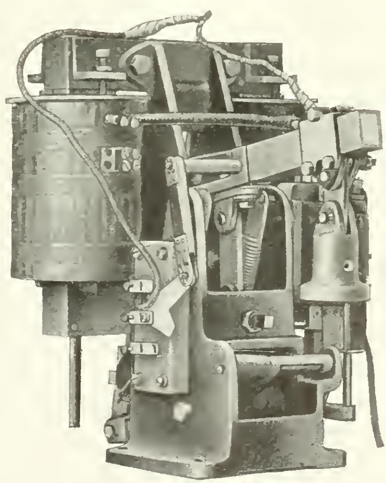


FIG. 3—MECHANISM OF OUTDOOR CIRCUIT BREAKER

Instantaneous action—The coil exerts its power at the instant current is turned on, while the motor must accelerate somewhat before it can deliver much power.

Straight line motion—Nearly all circuit breakers close in a straight line and it is comparatively easy to arrange lever systems with straight line motions. On the other hand, a motor is a rotating device, running at high speed and requiring gearing, cranks, etc.

Absence of bearing and commutator troubles—Inasmuch as a solenoid consists simply of a coil and core, there should be very little wear of parts.

Absence of insulation troubles—Stationary coils can be insulated for nearly any voltage while rotating coils, on account of space, mechanical strain, etc., are much more difficult to insulate. In short, the solenoid acts at once, through simple levers without gearing or commutators, is heavily insulated, is without moving wires or contacts, and is practically permanent.

Pneumatic operation—Some notable installations of switching devices, including circuit breakers, have been made in which the actual power for operating the apparatus is compressed air. The principle of straight line motion and its accompanying simplicity has led to the development in the railway field of multiple-unit control systems using such power. As, however, compressed air is required for air brakes, the expense of the compressor, etc., is not wholly chargeable to the control system. The use of compressed air for this purpose has proven most successful, as there is thus sufficient power available to give high contact pressures, together with the added advantage that this pressure is elastic and constant and can be maintained without further expenditure of energy. The applications of these principles to power stations, however, has not been strikingly successful, in the few cases in which it has been tried. In fact, there have been no recent applications of especial note. The problem is somewhat different from that of car control, due to the fact that compressed air is not needed for other uses, that the apparatus is much more scattered and that the conditions of operation are more favorable as regards weather, dirt, and wear and tear. Such operation would probably be much more expensive than electrical, due to both the initial and maintenance costs and the additional cost of pneumatic equipment for the circuit breakers themselves. This system has possibilities, however, and may be further developed as new conditions arise.

MULTIPOLAR OPERATION

Circuit breakers are arranged for both single and multipolar operation, i. e., they must be capable of disconnecting one line or several. Carbon break circuit breakers which are used on low voltages are often made single-pole, an ordinary knife switch being used to disconnect the other side of the line. Double-pole circuit breakers are similarly used on two-phase, four-wire circuits, the circuit breakers opening both phases on one side and a double-pole knife switch being installed in addition to open the other side. There is thus a considerable saving in expense but, of course, only partial protection is obtained.

On circuits of 2 200 volts or over open switches are out of the question and oil circuit breakers are generally employed. It is necessary, for this service, to arrange the circuit breakers so that they will entirely disconnect all circuits. Single-pole oil circuit breakers are therefore rarely asked for and are not at present listed by manufacturers. An exception to this rule is the circuit breaker used with manhole transformers. Most underground high tension systems are three-phase, star-connected, the fourth wire being grounded and the transformers connected between each phase and this ground. With this arrangement, single-pole protection is quite satisfactory. For a similar reason, oil circuit breakers used in single-phase railway work are single-pole.

"Non-closable on overload" feature—Where multipolar circuit breakers are used, they may be arranged to close simultaneously or to have each pole closed separately. In general, it is desired to have all poles open together. On direct current-circuits a single-pole circuit breaker is often installed in each line. One circuit breaker is then closed, and upon closing its mate, if a short-circuit exists, the former opens. This feature of "non-closable on overload" is desirable in some cases and is also made a feature of many types of circuit breakers by suitable arrangement of the mechanism. In English practice, such circuit breakers are designated as "Double-handle." They are so arranged that if closed on overload they will open, even if the operator holds the handle in the closed position. This is accomplished in a number of ways, all of which depend upon the use of some latch or toggle device, which connects the operating handle to the mechanism proper. In case of an overload this latch is opened and disconnects the mechanism entirely from the handle regardless of its position. The principal objection to this feature is that, where there is a momentarily heavy rush of

current at the instant of closing, it is impossible for the operator to hold the circuit breaker closed until the current has decreased, whereas it is often very desirable to be able to do so, as when starting induction motors. The addition of this auxiliary mechanism necessarily complicates a circuit breaker and for low tension apparatus it has not found much favor in this country as switches are generally used in addition, and, by closing the circuit breaker before the switch, the same end is accomplished. Where the switch is dispensed with, however, it is a desirable or even necessary feature.

TIME LIMIT FEATURES

It is often desirable to prevent instantaneous action of breakers inasmuch as heavy momentary overloads are not harmful and as it is desirable to maintain continuity of service. The time features may be "definite" or "inverse."

With a definite time element, the circuit breaker will open in a certain specified time, when a predetermined condition occurs, regardless of the intensity of that condition. With the overload definite time element, set for ten seconds at 1 000 amperes, the circuit will be opened in ten seconds at that current or one of any higher value.

An inverse time element would open in ten seconds at 1 000 amperes, and with higher values of current in a correspondingly less time, that is, in an inverse ratio to the current. For example, the time interval before tripping with a current of 2 000 amperes would be about seven seconds, with 3 000 amperes, five seconds, etc. By the use of such attachments, the circuit breakers of a system may be made selective in their action.

Suppose it is desired to arrange a system so that a short-circuit on any one feeder will open the feeder circuit breaker, but not the main circuit breaker. By making the feeder circuit breakers plain overload and putting time elements on the main circuit breakers, the feeder circuits will be the first to be opened. In cases of short-circuit, both will open, but on ordinary overloads, the main circuit breaker will not open. This is a desirable arrangement, inasmuch as the shutting down of a whole plant, as the result of trouble on only one part, is thus avoided. Another common use for the time element is in connection with motors with peak-loads which greatly exceed their safe continuous capacity. In this case with an overload inverse time element, ample protection can be given the motor while permitting these momentary overloads. This whole subject

of time element protection is very interesting and theoretically very desirable. It introduces additional complications, however, and in practice is not so desirable. In retarding the action of a circuit breaker there is always a danger of entirely arresting the action. Moreover, most time element devices on the market depend on air bellows or dashpots. The air bellows are most satisfactory, inasmuch as oil, glycerine, etc., are liable to atmospheric and temperature changes.

CALIBRATION

By calibration is meant the adjustment for different values of tripping current. The standard range on some makes of circuit breakers is from 80 to 160 percent of full-load current. These values are satisfactory for ordinary conditions and provide sufficient range for nearly all classes of service. The calibration is effected either by varying the air gap of the magnetic circuit or varying the weight to be lifted. For a given current with a given number of turns on a circuit breaker coil, the ampere-turns are, of course, constant. In circuit breakers operated by coils it is evidently possible, by varying the number of turns, to make the normal trip of the circuit breaker almost any value. It is found, however, on the carbon break type that 1 000 ampere-turns give sufficient power to operate the tripping mechanism and the coil is unnecessary on circuit breakers of 1 000 amperes and over, the single turn formed by the studs and the brush being sufficient to produce this value. The principle points desired in calibration are accuracy, permanency, ease of reading and simplicity of adjustment.

The accuracy desired for different classes of service varies and a very poor calibration would probably be sufficient for the majority of them inasmuch as circuit breakers are set for abnormal conditions. There is no reason, however, why a circuit breaker should not be calibrated very closely. A more important requirement is that an adjustment, once made, shall be permanent under all conditions. A long open scale and ready means of making settings are also desirable.

OVERLOAD CAPACITY

Circuit breakers are generally rated on the basis of a twenty degree C. rise at full-load. They will carry very heavy overloads for a few seconds and ordinarily follow the general law applicable to all devices in which heating alone is the limiting factor, i. e., that the energy to be dissipated increases as the square of the cur-

rent. This energy is either absorbed by the material as heat or is radiated. If the current is maintained constant for a long period the specific heat of the material does not figure. For short periods, however, it is an important matter and the more material the device contains the better it can stand short overloads. Switching devices in general contain considerable copper and therefore have comparatively good characteristics. Fig. 4 shows a characteristic curve of heat-absorbing capacity of a certain device. In this figure, curve *A* shows the heat-absorbing capacity alone or that due to the specific heat of the material, while curve *B* shows the corresponding actual curve with radiation added. This device will carry continuously only fifty amperes at twenty degrees C. rise, but it will carry 100 amperes for thirty seconds and 200 amperes for five seconds. For one second such a device would carry 1 000 percent overload.

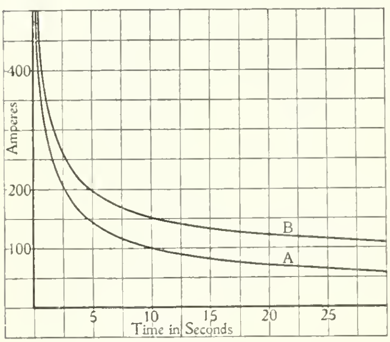


FIG. 4—CURRENT-TIME CURVES

A rise of twenty degrees C. is commonly specified in switchboard practice and is very low compared with the temperature which circuit breakers will carry without damage to themselves. The limiting factor with oil circuit breakers lies in the oil temperature, and with air circuit breakers, in the coil and brush temperatures, both of which may be manifestly much higher.

It is often desirable to know the probable heating due to continuous overloads. In the curves, shown in Fig. 5, the temperature rise of a circuit breaker designed to carry 100 amperes at 20 degrees C. rise is plotted. Curve *A* shows the temperature that would be reached by such a piece of apparatus if the radiation were proportional

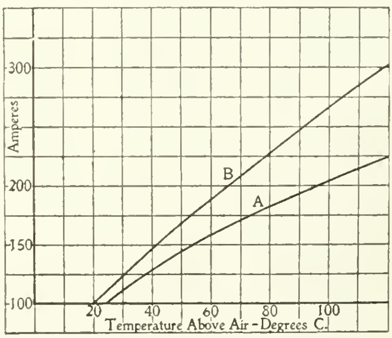


FIG. 5—CONTINUOUS CURRENT-TEMPERATURE CURVES

to the difference in the initial and final temperature. It is known, however, that the radiation increases much faster than the temperature, in fact, that for 100 degrees C. rise there is 1.68 times the radiation per degree that there is for one degree rise. Curve *A* must, therefore, be corrected for this increase. Curve *B* shows such a corrected curve which may be generally applied to all devices limited by heating. From this curve it will be seen that 150 percent full-load gives 41 degrees C. rise and 200 percent full-load gives 65 degrees C. rise. The amount of permissible rise, however, is governed by the particular conditions of a given case.

CURRENT BREAKING CAPACITY

It seems reasonable to expect that every circuit-breaker has an ultimate maximum amperage which it will open without damage

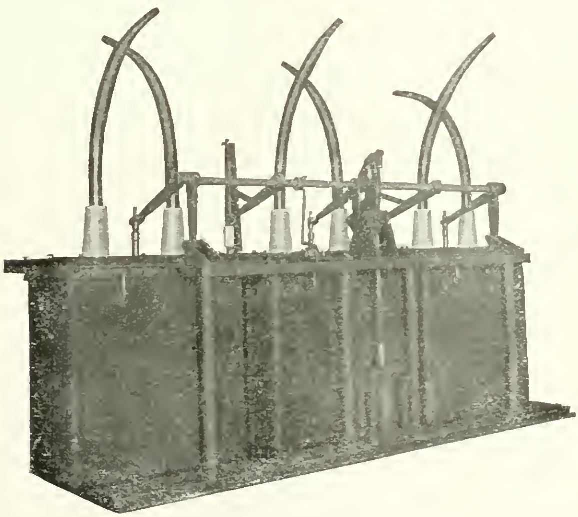


FIG. 6—OIL CIRCUIT-BREAKER

Three-pole, electrically-operated type for heavy capacity service

to itself. There are, however, circuit breakers which have never reached this maximum, due to the fact that sufficient power is not available. Short-circuits, even on 60 000 volt lines with 200 000 kw behind them, are limited by transformer and generator characteristics and impedance of line. A circuit breaker of the type shown in Fig. 6 has repeatedly opened such short-circuits without difficulty. Obviously, the best way to rate a circuit breaker would be

to state what amperage it would break. It is not easy on any system to say what this ultimate short-circuit value is, and the better way seems to be to rate circuit breakers on the basis of total generating capacity liable to feed a short-circuit. This is commonly called "Ultimate breaking capacity."

In the case of fuses, an attempt has been made by the National Board of Fire Underwriters, to define the circuit characteristics that must obtain where tests are made. This is covered by section *K* of rule 53 of the National Electrical Code, edition of 1907. This rule is at best only a make-shift, as it is very severe on small cheap apparatus which, while incapable of standing the test conditions, would be commercially satisfactory. It is, moreover, unsatisfactory in that it gives but one rule for testing all fuses and does not attempt to limit their applicaion, it being assumed that inspectors in general cannot be given sufficient latitude to make such a course possible. It says, in effect, that every enclosed fuse must open a short-circuit of 10 000 amperes. It is evident that in a small isolated plant of 150 kw, any such short-circuit is impossible, while in a large railway power plant, short-circuits much in excess of this may occur.

No such ruling has been made in the case of circuit breakers, however, and the method of rating a breaker by normal voltage and amperage and by limiting the total kw of the system to which it may be supplied is much more logical.

PROTECTIVE RELAYS (Cont.)

M. C. RYPINSKI

DIRECT-CURRENT REVERSE CURRENT RELAYS

INSTANTANEOUS ACTION

THIS type of relay operates on reversal of current and is illustrated in Fig. 11. It is used for the protection of small battery installations and for other reverse protection not requiring operation below a reversal of 25 percent of the normal current. It is used chiefly in connection with small circuit breakers where the use of the reverse current relay hereinafter to be described is prohibited by its higher cost.

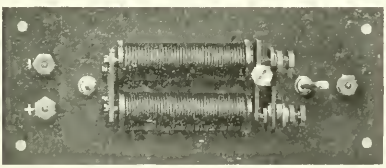


FIG. 11—DIRECT-CURRENT REVERSE CURRENT RELAY

It is of the instantaneous polarized construction identical with the over-voltage type of relay previously described, except that its coils are wound with fewer turns of larger wire; it is non-adjustable, has no external resistance and requires one or two ammeter shunts for its operation. Its action is similar to that of the over-voltage type, except that connections are made so as to cause closure of the trip contacts upon the reversal of the current. The relay operates when 25 millivolts are applied to its coil terminals. One ammeter shunt with a full-load drop of approximately 50 millivolts will thus cause the relay to operate on 50 percent reversal. Two ammeter shunts in series will give 100 millivolts and will cause operation on 25 percent reversal. This type of relay is connected as shown in Fig. 12. The use of shunts may be avoided by using instead an equivalent length of bus-bar or cable. On a basis of 1 000 amperes per square inch, six feet of copper bus-bar will give 50 millivolt drop. A greater

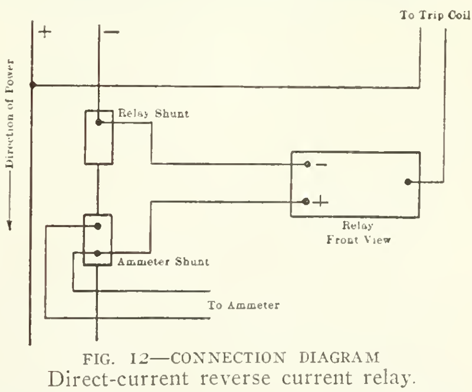


FIG. 12—CONNECTION DIAGRAM
Direct-current reverse current relay.

drop than 100 millivolts should never be used, as it would endanger the relay coils. The relays should be connected to their shunts by a pair of insulated copper wires of at least No. 8 B. & S. gauge or its equivalent when the distance between the relay and the shunt does not exceed 150 feet. For greater distances, the leads should be proportionately larger. The operation of one of these relays from the same shunt as an ammeter does not impair the accuracy of the latter.

INVERSE TIME ELEMENT ACTION

The function of this type of relay (Fig. 13) is to protect direct-current apparatus against current reversal. They have an inverse time element action, are adjustable as to current setting, but will not operate on alternating current. They are used chiefly for the protection of storage battery installations and rotary converters. When applied to rotary converters operating in parallel they serve to protect against short-circuits occurring on the alternating-current side of the rotary, on the direct-current side between the rotary and the relay or in the rotary itself. Short-circuits occurring on the direct-current side beyond the relay are taken care of by circuit breaker overload coils.

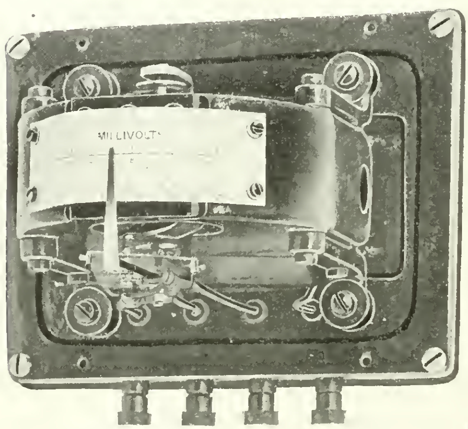


FIG. 13—DIRECT-CURRENT REVERSE CURRENT RELAY WITH INVERSE TIME ELEMENT ACTION
Metal case removed.

When synchronizing machines to a system operating rotary converters, momentary and harmless corrective currents are liable to flow toward the rotaries on the direct-current side. In order to prevent interruption of the circuit by such flow, where reverse current relays are present, it is necessary that the latter have a time element. This element may be of the inverse order to give quick interruption on overloads and short-circuits and to give a selective action so as to cut off affected areas.

Reverse current relays are not to be recommended as a complete protection against overspeeding and running away, such as would

result from the opening of the field of a rotary converter. They should be supplemented by mechanical overspeed devices attached directly to the shaft of the converter and arranged to close the trip circuit upon operation. Such additional precaution is necessary as very low reverse currents exist under such conditions, only sufficient to supply the losses in the rotary and less than the minimum setting

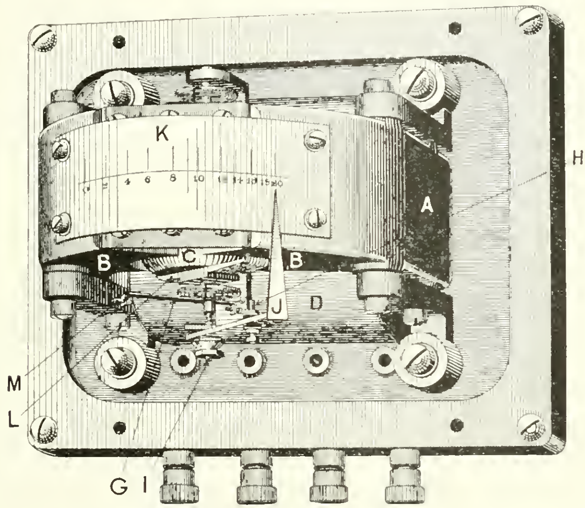


FIG. 14—CONSTRUCTION DETAILS OF RELAY SHOWN IN FIG. 13

A is a bi-polar electro-magnet of soft iron with concave pole faces *B-B*.
C is a cylindrical soft iron core, stationary and located concentrically between *B-B*.
D is a stationary field coil magnetizing *A* above its saturation point. A moving coil *E*, suitably pivoted and mounted, rotates in the annular air-gap between *B-B* and *C* against the controlling action of the spiral springs *F-F*.
E carries a constant arm *G* provided with a contact *M*, which in rotating travels against the stationary contact *H*, the latter being pivoted to *I* so that it can be adjusted by means of the index arm *J*.
J travels over a scale *K* which is graduated from two to 20 millivolts.

on the reverse current relay, which will therefore fail to operate and protect the machine.

PRINCIPLE OF OPERATION

In principle this type of relay is similar to a permanent magnet, moving coil ammeter operated from a shunt except that the permanent magnet is here replaced by an electro-magnet. The winding of the electro-magnet is connected across the line and has its iron core highly saturated. The moving coil is connected across a shunt in series with the line so that with current flowing through the circuit in its normal direction a contact carried by the moving coil is held

away from a corresponding stationary trip circuit contact. Upon reversal of the current the moving coil reverses its direction, thereby closing the trip circuit, providing the current is sufficiently great to overcome the torque of a controlling spring tending to keep the contacts open. The angle through which the moving coil has to travel to close the contacts can be varied by moving the stationary contact and varying the amount of twist of the controlling spring which must be overcome by the relay current in order to close the contacts.

The coil *E* (Fig. 14) is wound on an aluminum frame *L*. The movement through the magnetic field of this frame generates in its conducting mass eddy currents which, reacting with the magnetic field, oppose and retard the motion of the frame. As the retarding action varies inversely with the speed of rotation and therefore with the amount of current flowing in the coil *E*, it may be seen that this damping frame supplies the inverse time element feature of the relay. The method of connecting this type of relay to a circuit is shown in Fig. 15. The adjustable index, shown in Fig. 14, should be set at such a millivolt graduation on the scale as will agree with the drop in the shunt or bus-bar when the desired minimum reverse current is flowing.

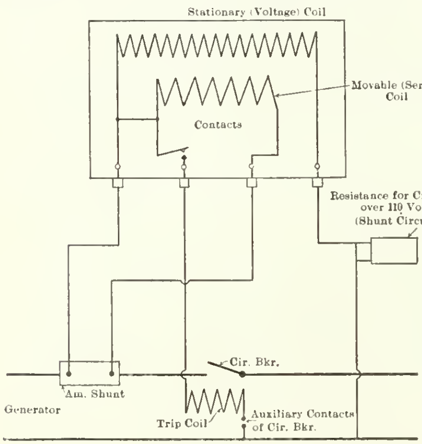


FIG. 15—CONNECTION DIAGRAM
Direct-current reverse current, inverse time element relay.

As the field of the relay is saturated, ordinary changes in voltage do not affect its action. This is well illustrated by Fig. 16, in which is shown a series of curves corresponding to various conditions of setting. Reference is particularly made here to curves *B* and *B'*, the former being a curve showing the relation at normal voltage between the time taken for the relay to act and the impressed millivolts, the relay being set for five millivolts; the latter showing the effect of a change in the voltage to fifty-nine per cent. of the normal, all other conditions being maintained the same. It may be seen from the curves that this change of forty percent in voltage causes less than ten percent change in the operation of the relay.

The curves also illustrate the inverse action of the clamping frame. From curve *A*, for example, it may be seen that, with a two millivolt setting and two millivolts applied, eight seconds are required for the relay contacts to close, while with sixteen millivolts applied, only one-sixteenth of the time or one-half second is needed. The maximum time element which the relay will give is eight seconds.

The field windings of relays of this type are ordinarily for 100-130 volts. For 200 volts and for 500 volts an external series resistance may be used.

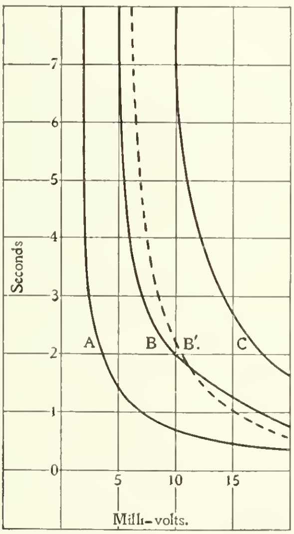


FIG. 16 — CURVES SHOWING OPERATION OF RELAY AT VARIOUS SETTINGS AND WITH VOLTAGE LOW

An ammeter shunt of capacity suitable for the circuit for connection to the series winding is necessary. Where an ammeter shunt is already installed, the relay may be operated from it without impairing the accuracy of the ammeter, or a section of bus-bar sufficient to give a drop of fifty millivolts may be employed. On the basis of 1 000 amperes per square inch, six feet of copper bus-bar will give fifty millivolts drop. The ordinary switchboard ammeter shunt has a drop at full capacity of approximately fifty millivolts. The relay would, therefore, give a minimum trip at two millivolts or four percent reversal. If two percent reversal is desired, two shunts may be installed in series and the relay connected across both. More than two shunts or 100 millivolts should never be used. The generator type of shunt used on three-wire generators and installed on the terminal board of such machines has a drop at full capacity of approximately seventy millivolts.

(*To be continued*)

SINGLE-PHASE ELECTRIC RAILWAYS

M. N. BLAKEMORE

MUCH information has appeared from time to time in various technical journals, giving data as to the advances that have been been made in the single-phase railway field, but nowhere has there appeared a concise, comprehensive statement of what has actually been accomplished. It is to fill this gap that the writer has been prompted to gather this information together and present it in condensed form. It is interesting to note the rapid strides which this phase of the art has taken since it first appeared commercially in 1903. It may cause some surprise when it is stated that one company alone has already filled orders for more than fifty locomotives, all of which were designed for operation on single-phase alternating current, while of this number, considerably more than half were adapted for both alternating and direct-current.

In addition to the locomotives indicated in the table, several other special ones have been built for operation on alternating-current. Of these might be mentioned the 135-ton single-phase locomotive for the Westinghouse Inter-Works Railway, and the 70-ton 15 cycle alternating-current locomotive which is now being tested by the Pennsylvania Railroad.

All of the installations mentioned are operated from a single catenary trolley, with the exception of the New Haven road, which uses the double catenary line construction. The pantagraph trolley is almost exclusively used in this country, although a sliding bow trolley, somewhat similar to that so common abroad, has been tried, but is not so successful as the pantagraph type of trolley. This is due to the fact that the sliding bow trolley does not respond so readily to the varying heights of wire as does the pantagraph trolley.

SUMMARY

Total number of Roads	MILEAGE			Total number of Cars	Total number of Locomotives	Total h.p. of motors employed
	Total	In Operation	Under Construction			
28	966.3	691.8	274.5	240	57	137 400

The table is prepared from data secured through the courtesy of the Westinghouse and General Electric Companies, and contains much information regarding the roads in this country equipped with

single-phase apparatus. The main features of the table are given in the summary. In the table, the mileage given is simply the length of the road and does not take into account the fact that some may have two, three or four tracks electrified. If an accurate statement could be made, the mileage would be considerably increased.

DATA ON SINGLE-PHASE ELECTRIC ROADS IN AMERICA

NAME OF ROAD	Length (Miles) of Line Electrified	Equipment: Cars No.	Cars Motors	Locomotives No.	Locomotives Motors	Type of Control Used	Line Characteristics: Voltage	Cycles	Electric Service Started
Westinghouse									
Indianapolis & Cincinnati Traction Co.	116	25	4-100	0		Unit Switch	3300 550	25 D.C	Dec., '04
Westmoreland Traction Co.	6.6	4	4-50	0		Hand	1200	25	March, '05
San Francisco, Vallejo, Benecia & Napa Valley Ry. Co.	34	2 8	4-75 4-100	0		Unit Switch	3300	25	June, '05
Atlanta Northern Traction Co.	18.2	8	4-50	0		Hand	2200	25	July, '05
Warren & Jamestown Street Ry. Co.	22.5	6	4-50	0		"	3300	25	Aug., '05
Long Island Railroad Co.	5	6	2-50	0		"	2200	25	Sept., '05
Spokane & Inland Ry. Co.	115	21	4-100	6 8	4-150 4-175	Unit Switch	6600 550	25 D.C.	Nov., '06
Erie Railroad Co.	34	6	4-100	0		"	11000	25	Dec., '06
Fort Wayne & Springfield Street Ry. Co.	21.5	4	4-75	0		"	6600	25	Jan. '07
Pittsburgh & Butler Street Ry. Co.	33	11	4-100	0		"	6600 550	25 D.C.	May, '07
New York, New Haven & Hartford Railroad Co.	22	0		35	4-250	"	11000 600	25 D.C.	July '07
Windsor, Essex & Lake Shore Rapid Railway	28	5	2-100	0		Hand	6600	25	Sept., '07
Grand Trunk Railroad Co. (Sarnia Tunnel)	3.5	0		5	3-240	Unit Control	3300	25	Under Const.
Visalia Electric Ry. Co.	23	4	4-75	1	4-125	"	3300	15	" "
Chicago, Lake Shore & So. Bend Ry. Co.	78	24 4	4-125 2-75	0		Unit Switch Hand	6600 575	25 D.C.	" "
Denver and Interurban Railway Co	46	10	4-125	0		Unit Switch	11000 575	25 D.C.	" "
Hanover & York Street Ry. Co.	20	5	4-75	0		"	6600 575	25 D.C.	" "
Shore Line Electric Ry. Co.	12	4	4-75	0		"	6600	25	" "
Maryland Electric Ry. Co.	24	9	4-100	0		"	6600	25	" "
General Electric									
Bloomington, Pontiac & Joliet Ry. Co.	19	2	4-75	0		K	3300	25	In Operation
Toledo & Chicago Ry. Co.	43	7	4-75	0		K	3300 575	25 D.C.	" "
Milwaukee Electric Ry. & Light Co.	59	11	4-75	0		M	3300 575	25 D.C.	" "
Central Illinois Construction Co.	80	20	4-75	1	4-150	M	3300 575	25 D.C.	" "
Richmond & Chesapeake Bay Ry. Co.	15	4	4-125	0		M	6600	25	" "
Anderson Traction Co.	20	3	4-75			K	3300 575	25 D.C.	" "
Washington, Baltimore & Annapolis Ry. Co.	60	21	4-125	0		M	6600 575	25 D.C.	Under Const.
New York, New Haven & Hartford R. R. Co.	8	4 2	2-125 4-125			M	11000	25	" "
Shawinigan Railway Co.		0		1	4-150	M	6600 600	30-15 D.C.	" "

ELECTRIC TRAIN PERFORMANCE

W. S. VALENTINE

Engineer, Westinghouse, Church, Kerr & Company

IN solving problems of electric train performance, the graphical method of expressing the relations existing between the many variables is of great assistance. This method has decided advantages over purely mathematical representations, by means of equations and tabulated figures, for the reason that it affords a picture of the manner in which one quantity varies in relation to another. The experienced eye can see almost at a glance the result of certain assumptions worked out and plotted in the form of a curve or set of curves. Errors may often be detected at once in a curve where they would be entirely overlooked in a table of figures.

It is the purpose of this article to describe a method in which, by the use of a celluloid templet, the amount of work entailed in the usual methods practiced by engineers, is greatly reduced. In any proposed electric traction service there are,—first, the fixed conditions, such as grades and curvatures of track and in the case of electrification of a road previously operated by steam, the length of run between stations and service requirements such as schedule speed and headway of trains.

The first step in solving such a problem is the selection of the proper motor equipment for the proposed service. Here the assumption is made, based on the previous experience of the engineer, as to the probable size of motor, and from the characteristic curves he is enabled to plot out the speed-time curves based on these assumptions, and make the selection of proper motor equipment. In conjunction with the speed-time curve, other curves such as current-time and distance-time curves are plotted.

One of the problems to be solved, in the preliminary design of a proposed electric road, is the determination of the amount of power that will be required to maintain the train service. By the usual method, this power is closely approximated by means of the speed-time and current curves, in the following manner: The train schedule will give the time which each train is allowed in making the run between stations. The distance between stations being known, the complete speed-time curve of each individual run may be drawn. Then, by integrating the area under the current curve, the power used is found. In the speed-time curve of a completed train

run between stations, it is generally necessary to allow a certain amount of coasting, so that the train will make the prescribed schedule speed. Hence it becomes necessary to know, before the speed-time curve is drawn, the exact area that the curve is to enclose as this area represents the distance between stations.

The rate of braking is assumed, sometimes as 1.5 miles per hour per second, and hence the backward slope of the braking curve is known and this part of the speed-time curve may be drawn from the point on the X-axis corresponding to the time of the train run. The next step is to determine how much coasting is necessary to enclose the correct area above mentioned. This becomes a cut and try method and if the engineer is expert he may hit upon the proper amount of coasting by two or three trials. This method, however, is tedious and necessitates the outlay of considerable time in drawing curves and integrating areas.

The graphical method described below will give the desired results without drawing the complete speed-time curve in each case, or integrating any areas. By means of this method it is possible to determine at what point in a speed-time curve power should be cut off and coasting and braking begun to give a certain schedule speed between stations.

It may be well to call attention to the composite character of a speed-time run of a complete train movement. There is, first, the acceleration period from the starting point to the point *A* (Fig. 1). At this point power is cut off and the train coasts freely to a point *B*. From this point on brakes are applied and the train comes to rest at *C*, having completed the run in 3.5 minutes and covered a distance of two miles. From the kw-minute time curve, which is also plotted in Fig. 1, the exact amount of power in kw-minutes which the train has consumed in making the entire run, may be determined. This kw-minute time curve bears the same relation to the current-time curve that the distance-time curve bears to the speed-time curve. In other words, it is found by plotting the values of successive areas of the current-time curve, these areas being reduced to equivalent values of kw-minutes, based upon an assumed constant voltage. The current-time curve is not shown in Fig. 1, as it is assumed that the reader is familiar with the usual form of this curve, and that it is better not to further complicate the diagram.

In the present case the road is assumed to be level and straight. The work is greatly simplified by making this assumption and the results, as a rule, are well within the usual error for this class of

work. This is especially so in cases where the proposed electric road is the electrification of a steam road, in which grades and curvatures are moderate.

As shown in Fig. 2 the coasting speed-time curve, for the particular equipment in question, is plotted from the starting point of 45 miles per hour, which is slightly more than the maximum possible speed of the train in question. At frequent intervals speed-time braking curves are drawn in. Next the coasting distance-time curve is drawn by integrating the area enclosed under the coasting speed-time curve. Then the distance-time curve is plotted for both coasting and braking for each of the suc-

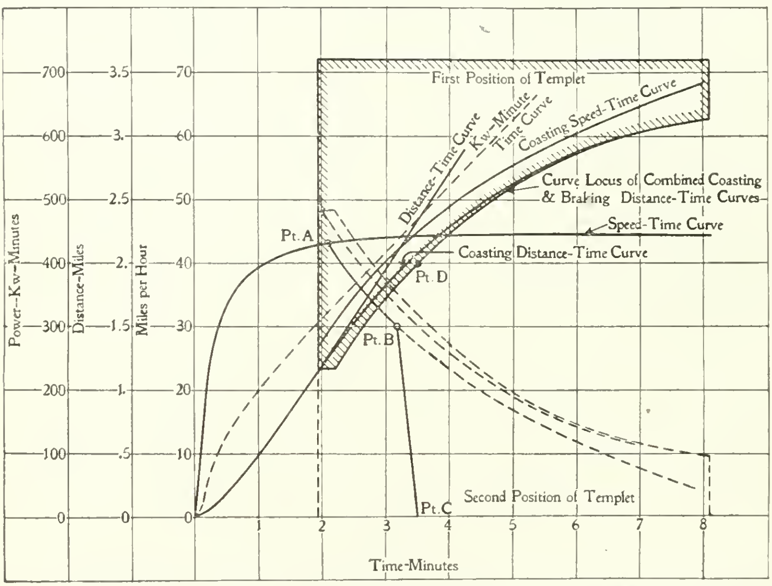


FIG. I—ILLUSTRATING USE OF TEMPLET IN INVESTIGATING TRAIN PERFORMANCE BY GRAPHICAL METHOD

cessive steps of braking. Through the terminal points of these coasting and braking distance-time curves, a smooth curve is plotted, as shown. It will be seen that this is a locus curve of any or all coasting and braking time distance curves. The next step of development is to make a celluloid templet. On this templet is inscribed the *coasting* speed-time curve, and the celluloid is trimmed so that its edges will coincide with the X and Y-axes of the curve. The templet is then inverted, still keeping the Y-axis of the templet on the Y-axis of the curve, and the two curves, namely, the coasting distance-time and curve locus of the combined coasting and braking

distance-time curves, are transferred to the templet. The final step is to trim the templet along the curve locus. It will then have the form shown in Fig I, where it is applied to a particular problem.

By means of this templet and the curves shown in Fig. I, the point, at which power should be cut off for any assumed distance and time of run between stations, may be determined.

EXAMPLE

Assume that it is desired to make a run with the equipment between stations two miles apart in 3.5 minutes. Insert a needle point at point *D*, which corresponds to these two assumptions of time and distance. Apply the celluloid templet so that the curved edge will always be in contact with the needle, and keep the *Y*-axis of the templet always vertical; adjust until the curve on the templet of distance-time for coasting is tangent to the curve of distance-time for acceleration, see *First Position of Templet,* in Fig. I. This point of tangency is the point at which the power is cut off and the train begins to coast. However, as a point of tangency is more or less indefinite it is necessary to perform a further step, which is as follows: Insert a needle at some point against the vertical edge of the templet, and then invert the templet so that its *X*-axis coincides with the *X*-axis of Fig. I, and its *Y*-axis touches the needle point, see *Second Position of Templet.* The point *A* at which the coasting speed-time curve on the templet crosses the speed-time curve in Fig. I is the point at which power should be cut off and the coasting should begin in order to make the run of two miles in exactly 3.5 minutes.

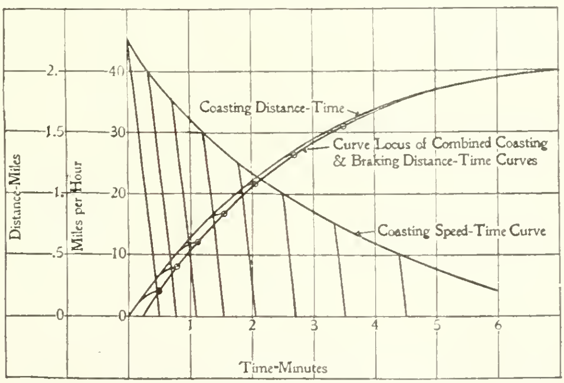


FIG. 2—ILLUSTRATING METHOD OF DETERMINING THE CURVE LOCUS TO WHICH THE TEMPLET IS SHAPED

It may seem that this is considerable preparation to go through with in order to determine simply this point at which power should be cut off; and so it would be if only one or two such determinations were required. However, in cases where there is a large number of such runs to be made with varying times and distances between stations, it will be found that the use of this method will afford a definite and accurate means of determining exact power requirements in making any assumed train schedule from one end of the road to the other, and that considerable time will have been saved over the usual method described above.

This method gives more accurate results than the method of computing the power from the average train run, and has the added advantage of giving the proper distribution of power between substations and also aids in the design of the feeder layout.

In cases where the distance between stations is so little that the train would not have an opportunity to come up to the point of multiple running it is considered that the train will only accelerate to the series voltage or half the maximum speed, and to meet this condition the chart in Fig. 1 may have plotted upon it a speed-time curve and a corresponding distance-time and kw-time curve for series running. The templet of coasting and braking are obviously the same for both series and multiple running.

RAILWAY LOCATION AND CONSTRUCTION

H. E. WAGNER

Member of Committee on Valuation N. Y., N. H. & H. R. R.

THE methods employed by engineers engaged in railway location, construction and maintenance have so changed that the modern railway engineer is no longer simply a locating engineer, or a construction engineer, but an engineer trained in all branches of railway engineering from the preliminary work of location to the operation of the completed road. A study of the location and construction of some of the present existing roads is sufficient evidence that the late A. M. Wellington (Author of "The Economic Theory of Railway Location") has correctly phrased it, "There is no field of professional labor in which a limited amount of modest incompetency can set so many picks, shovels and locomo-

tives at work to no purpose whatever." In the early days of steam railway location, the locating engineer paid little attention to the matter of railway operation, as such matters were considered rather outside of the province of the engineering department. Present operating conditions require revision and reconstruction of existing lines, and this now constitutes such a large proportion of railway engineering work in this country, that there has been opened up an entirely new field for the exercise of the special skill of the railway engineer. The modern locating engineer is of necessity experienced in construction and maintenance work, with at least a limited knowledge of conditions governing operation. The engineer most valuable to any railway is the man who has been trained in all the departments of railway engineering work. In his connection with the maintenance department he becomes familiar with conditions governing operation. After having gone through this school, he is prepared to specialize in one of the three branches,—location, construction or maintenance.

In order that engineering graduates may be properly trained to fit themselves for the higher positions in railway service, several railway companies have arranged an apprenticeship course whereby young men are taught railway work from the duties of track laborer to that of division superintendent. Such an apprenticeship course was inaugurated by Mr. J. F. Wallace a number of years ago on the Illinois Central Railroad, and worked out very successfully under his direction.

LOCATION

Upon the genius and skill of the locating engineer, depends the economy of location. The first step towards the location of a road is a reconnoissance by the locating engineer himself, often made on horseback. With an idea of how much his line should cost per mile, he determines on several possible locations. He must realize the nature and value of conflicting interests involved in each possible route. Before the location can be definitely decided it is also necessary that the factors governing the earning power be properly understood, and the relation between the purely engineering and the financial features thoroughly grasped. A railway that can furnish the most economical transportation will show the best earnings, and the principal factors which affect profits are, in a great measure, dependent upon the location of the road with regard to sources of traffic and economy of construction. For a

given amount of traffic with the proper location of the road, the greater the first expenditure the less will be the operating expenses, but the greater the fixed charges. Increasing the one decreases the other, and the economic location of the road is the one which makes the sum of the two a minimum.

The above conditions enable the engineer to determine the minimum allowable grade and curvature to be used. The cost of construction increases with the decrease of grades and curvature.

Following the reconnaissance comes the preliminary survey which furnishes the locating engineer with the necessary data to determine approximately the location to be selected. The final location of the road will be as nearly as possible on the natural contour

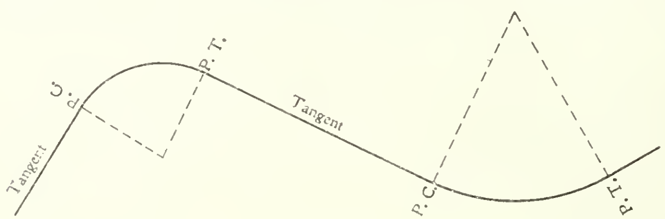


FIG. 1

of the ground corresponding to the maximum rate of grade adopted. Curves are employed to connect straight lines in changing direction to follow that contour. *The alignment* is a series of arcs of circles and tangents to the circles designated as curves and tangents. Each tangent is common to two arcs or curves. (Fig. 1.)

CURVES

In American practice a curve is designated by the number of degrees of angular measure subtended at the center of the circle by a chord of 100 feet (Fig. 2). A 1°—0′ curve is a curve of such a radius that a chord of 100 feet subtends a central angle of one degree, while a 3°—0′ curve has a radius such that a chord of 100 feet subtends a central angle of three degrees. The radius of a 1°—0′ curve is 5 730 ft. and the radius of a 3°—0′ curve is 1 910 ft.

The maximum allowable curvature on new construction of trunk line steam railroads now seldom exceeds 3 degrees. In street railway work, where curves of small radius are necessary, the curves are often designated by the radius instead of the degree of curve.

On tangents the rails should be perfectly level, while on curves the outer rail is elevated sufficiently to neutralize the centrifugal force of the train, which varies with the degree of curvature and

TABLE I—SUPER-ELEVATION FOR CURVES

Degree of Curve	Speed in Miles Per Hour						
	10	20	30	40	50	60	80
	Super-elevation of Outer Rail in Inches						
1		1/4	3/4	1 1/4	1 3/4	2 1/2	4 1/2
2	1/4	1/2	1 1/4	2 1/4	3 1/2	5	7 1/2
3	1/4	3/4	2	3 1/2	5 1/4	7 1/2	
4	1/2	1	2 1/2	4 1/2	7		
5	1/2	1 1/2	3 1/4	5 3/4	8 3/4		
6	1/2	1 3/4	3 3/4	6 3/4			
7	1/2	2	4 1/2	7 3/4			
8	1/2	2 1/4	5	9			
9	1/2	2 1/2	5 3/4				
10	3/4	2 3/4	6 1/4				
11	3/4	3	7				
12	1	3 1/4	7 1/2				
13	1	3 1/2	8				
14	1	4	9				
15	1 1/4	4 3/4					

the speed. Table I. gives the super-elevation for different speeds and curvature. It is not considered good practice to elevate any curve more than seven and one-half inches.

Where the track passes from tangent to curve the direction and super-elevation change suddenly. To avoid the shock and lurch of the train, due to an instant change in the relative position of cars, trucks, etc., an easement is made from tangent to curve. This ease-

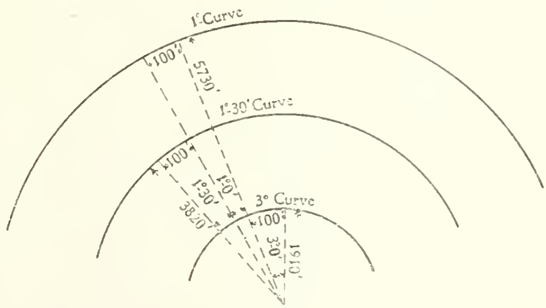


FIG. 2

ment allows the train to take the path of a spiral, i. e., the degree of curve increases at regular intervals from tangent to curve until the maximum degree of curvature, or that of the simple curve, is reached. Where it is possible, the length of this spiral (in feet) is usually made fifty times the degree of curve which is being approached. The corresponding easement in elevation covers the en-

tire length of the spiral, being zero at the beginning and increasing to the maximum super-elevation, for the simple curve, at the end of the spiral.

It is sometimes necessary to find the degree of a curve on a completed track, which can be done by the use of a tape, by the following method:

Some convenient point as a joint at "C" (Fig. 3) is selected. By sighting along the gauge on the gauge side of the outer rail side of the inner rail, find the point A. The distance AC can be measured and compared with the values given in Table II, which will give the degree of curve.

TABLE II—FOR FINDING DEGREE OF CURVE

Deg. of Curve.	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°
Length of *AC* in feet........	463	328	268	232	208	190	176	164	155	147	140	134	129	124	120

Some convenient point on the outer rail as *C* (Fig. 3) is selected. From the gauge side of the outer rail at *C*, sight along the gauge side of the inner rail on the line *CD*. The point *A*, where the line *CD* produced cuts the gauge side of the outer rail again, is thus determined, and the distance *AC* is measured. The length *AC* is now compared with the values given in Table II. and the corresponding degrees of curve in the table will be the value sought. The values given in the table for *AC* are the long chords corresponding to a constant middle ordinate (equal to the gauge of the track which, in this case, is 4 ft. 8.5 in.). The distance measured may vary several feet from that found in the table due to the inaccuracy of the alignment of the track, but since curves are always made in even degrees, except in special cases where local conditions make it necessary, the degree of curve can almost always be determined by the above method in a very short time.

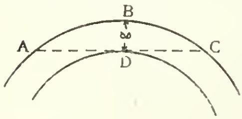


FIG. 3

TURNOUTS

A turnout is an arrangement by means of which a train may pass from one track to another. The term "switch" is often incorrectly applied to a turnout. The principal parts of a turnout are a switch, a frog and the necessary connecting track between the two. The frog is a union of two rails which cross each other. The switch is the movable part of the turnout and is the means of shifting the route at the entrance of the turnout.

Switches are of two kinds, stub and split. Stub switches are no longer manufactured and are now found only in unimportant yard tracks. The split switch (Fig. 4) consists of a pair of switch

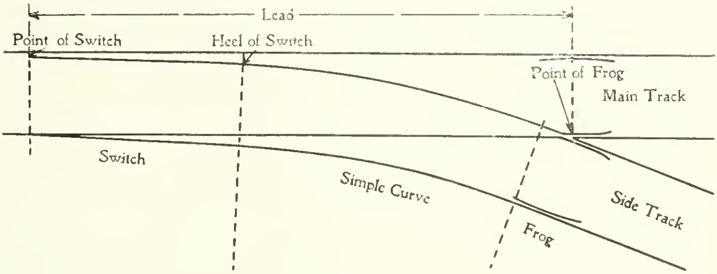


FIG. 4

points, varying in length from about eleven to thirty feet (depending on the length of lead of the turnout), and the necessary connecting rods, etc. The lead of a turnout is the distance from the point of a switch to the point of the frog and is dependent on the "number" of frog adopted.

FROGS

Frogs are designated by their number, n, which is the ratio of the length to the spread between the gauge lines. In Fig. 5, $n = FP \div CD = EF \div (AB + CD)$. Care should be exercised to measure AB and CD between the gauge lines. This method has been

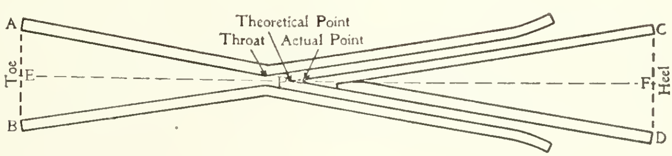


FIG. 5

adopted because of the simplicity of dealing with the ratio n rather than with the angle of the frog. Table III. gives the angle of the frog, i. e., the angle CPD, for the different values of n, also the degree of the turnout curve and the lead for the given length of switch and frog. In this table the values are derived by considering the switch rails and frog as being straight over their entire lengths, and the simple curve connecting the two. As a matter of convenience most roads adopt a few frogs as their standards,

usually No. *10* for frequently used turnouts from the main tracks and No. *7* or No. *8* for yard tracks. No. *20* frogs are often used for high-speed turnouts. For turnouts on curved main track, the degree of the turnout curve is increased by the amount of the curvature of the main track when on the inside, and decreased by the same amount when the turnout is on the outside of the curve.

CROSS-OVERS

Cross-overs between two parallel main tracks are figured as two turnouts connected by a tangent from curve to curve and mak-

TABLE III—SWITCH LEADS

No. of Frog	Length Toe to Point	Angle of Frog	Length of Switch	Degree of Curve	Lead
4	3′-0″	14°-15′	11′	49°-46′	40′
5	3′-0″	11°-25′	11′	29°-41′	46′
6	3′-0″	9°-31.5′	13′	19°-58′	54′
7	3′-0″	8°-10′	13′	14°-10′	60.5′
8	6′-6″	7°-.09′	15′	11°-54′	63.5′
10	6′-6″	5°-43.5′	15′	6°-54′	74.5′
20	9′-6″	2°-52′	30′	1°-40.5′	150′

ing an angle with the main tracks equal to the frog angle. In the case of cross-overs on curves, or between parallel straight tracks some distance apart, the connecting tangent is usually supplemented by a reverse curve. In making calculations for turnouts it should be borne in mind that the calculations are for the theoretical frog point instead of the actual frog point. Frogs are usually manufactured with a thickness of one-half inch at the actual point. Table III. gives length of lead and frog from the actual point.

EXPERIENCE ON THE ROAD

AN AMMETER TROUBLE

C. A. LEQUESNE, JR.

IN a private lighting plant there was an ammeter which was supposed to show the total current drawn from the lighting bus. There was also a similar ammeter to show the current drawn from the power bus. The lighting bus ammeter readings did not agree, by several hundred amperes, with the sum of the readings of the individual ammeters of the generators connected to the bus, and before the cause was discovered and remedied, it had the engine room force, a good portion of the owners' engineering department and the makers of the instrument guessing for several months.

Comparison of the generator ammeters, singly and collectively, with the power bus ammeter indicated that these instruments were very nearly correct, so the lighting bus ammeter was blamed for the trouble and sent back to the maker to be overhauled. In a week or two the instrument was re-installed and found to be no nearer correct than before, so it was again returned to the maker. This time the maker reported that there was nothing the matter with it and sent in a bill for overhauling and recalibrating it. The owners stated the facts and refused to pay the bill. The instrument maker's engineer then called upon the engineer to whom the matter had been referred and suggested that a wrong connection was probably the cause, but an examination of the wiring diagram of the switchboard disclosed none. He then suggested that possibly a stray field was the cause and together with an assistant of the owners' engineer examined the back of the switchboard for wrong connections and stray fields; but they didn't notice any, and gave it up.

The lighting bus consisted of four bus-bars; +, —, and equalizer (to which the generators were connected by means of three-pole switches) and a fourth bar to which the feeder circuit breakers were connected. In the connection between the plus bus-bar and this fourth bar, the shunt of the offending ammeter was connected.

It was finally discovered that a new feeder which had been installed to re-inforce an old feeder was connected to the plus and minus generator bus-bars above the ammeter shunt, instead of to the fourth or feeder bar and the minus bus-bar as it should have been. When this was corrected, the trouble disappeared, and the instrument maker's bill was paid with apologies.

A FIELD REVERSAL

C. W. KINNEY

An interesting field reversal came to the writer's attention a few days ago in a power plant consisting of a 440-volt, 150 kw, belted three-phase generator, with a six kw, four pole, 125-volt, belted exciter. A few minutes before "shutting down time" the alternator lost its field. A hurried examination showed that the negative exciter lead was broken at the brush-holder, also that three of the pole pieces were north poles, and one south. The lead, when found, lay across the frame, apparently having dropped there when it broke, but without grounding. After the broken lead had been repaired, a short-circuit test with a telephone receiver showed the circuit between the two armatures clear.

The machines were then started up, but the exciter "picked up" the wrong way. The only direct-current apparatus available was a couple of dry batteries which the engineer explained, as he brought them out, were about exhausted. These were applied to the series field of the exciter. They would reverse the field in the air-gap, but as soon as they were disconnected the residual field still showed the wrong polarity. The batteries were then applied to the shunt field. The field in the air-gap was apparently neutral while the batteries were attached. This suggested a possible solution of the trouble. The batteries were connected in the shunt field circuit and then the machine was started with all the resistance in the rheostat cut out. After a few seconds the machine began to pick up in the right direction and was then ready to run.

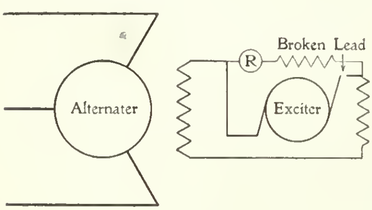


FIG. 1

The accompanying diagram shows the cause of the field reversal. When the field circuit of the alternator was broken it discharged through the shunt field of the exciter, the direction of the current being opposite to the normal.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

19—SHORT-CIRCUITS IN THREE-PHASE GENERATORS — In the editorial on "Grounded Neutral" in the December, 1906, JOURNAL it is stated that a short-circuit between one terminal and the neutral of a three-phase generator "results in a greater flow of current than would exist if there were a short-circuit between the terminals." Why?

The current in the armature of a short-circuited alternator is such that the ampere-turns in the armature are approximately equal to those in the field. A short-circuit between the neutral and one terminal includes fewer turns than does a short-circuit between the two main terminals, hence the current in the former case is greater than in the latter. Similarly, a short-circuit between all three of the main terminals of a three-phase generator causes a less armature current to flow than does a short-circuit between two terminals which include only a part of the winding.

20—LARGE INDUCTION MOTORS ARE TESTED in three ways:

1—With full-load conditions.

2—With full-load armature current at reduced voltage.

3—With full-load current circulating through the armature and machine run against normal conditions.

How do the temperature rises on the stator copper compare in the three cases?

With 1 as a basis, 2 will give a lower rise of temperature, due to the fact that the core losses are decreased; this effect is partly offset by the poorer ventilation due to lower speed. In case 3, since the secondary frequency is equal to that of the supply circuit times (1+s) (when *s* is the slip expressed as a decimal), the core loss in the secondary iron is very high and in consequence the secondary will run much hotter than under normal load conditions. Owing to the heat from the secondary, the primary copper will not run as cool as would otherwise be the case with lower core loss. All things considered, *3* gives a rise of the primary copper very nearly the same as under normal running conditions. I. E. H.

21—DELTA VS. "V" CONNECTION FOR INDUCTION MOTORS—If I were to use two single-phase transformers in connecting one three-phase 200-volt sixty-cycle motor in one building, and at another building I made another connection using three single-phase transformers, would there be any difference in the current consumption of the two motors? If so, please state which would be the most economical and how much. Also in using two single-phase transformers would I get full three-phase on the secondary? If not, why is it so many companies use this method? W. S.

If two single-phase transformers connected in V are used to operate one three-phase motor and three single-phase transformers connected in delta are used to operate a similar motor, there will be no difference in the current consumption, provided they are equally loaded, because the motors are independent of the means of supply as long as three-phase current is provided. The ideal method of operating the motor would be with the three single-phase transformers connected in delta. If one of the transformers in the group be removed without disturbing the other two, the two transformers will be connected in V. From Figs. 21 (a and b) it may be seen that the presence of the third transformer is not necessary to a true three-phase transformation. However, the V-connection is open to the

disadvantage that the combined capacity of the transformers must be approximately 15 percent greater than that of the three delta-connected

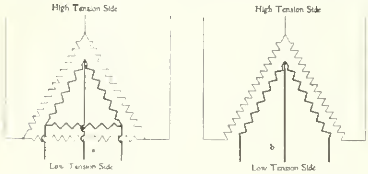


FIG. 21 (a) FIG. 21 (b)

units. This is due to a phase difference of thirty degrees between the current and voltage in the former transformers. E. G. R.

22—Does a UNIPOLAR GENERATOR have any eddy current loss in the iron? If not, why not? G. D. B.

Yes, though not large. No eddy current losses would imply absolutely uniform magnetic fields which it is practically impossible to secure. W. A. D.

23—DELTA AND STAR CONNECTION OF BOOSTER TRANSFORMERS—I have noticed in an article on using transformers for boosting the voltage of a three-phase circuit, the following: "The ratio of the boosting transformers being 10 to 1, a ten percent boost is obtained by connecting the primaries in star fashion, the secondaries being in series with the respective legs of the circuit. With the primaries connected delta fashion, no change being made in the secondary connections, the boost is about 15 percent." My understanding is that it is just the other way; that is, when the primaries are connected in star the boost is 15 percent, and when in delta, 10 per cent. Will you kindly advise me which is correct? I would also like to have a rough sketch of the delta connection of transformers for boosting three-phase. V. S.

Your understanding of the relative boost resulting from the star and delta connected transformers is incorrect. If the booster transformers have a ratio of 10 to 1, the star-connected arrangement will produce an increase in voltage of approximately ten per cent. or 220 volts with the circuit shown. The delta connected transformer will produce a boost of 15 percent or 380 volts. It will be

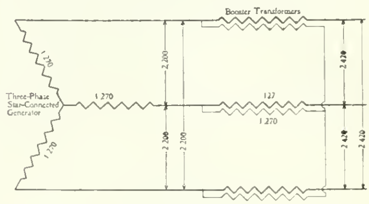


FIG. 23 (a)

noted that the ratio of the boost voltages is the ratio of the star and delta

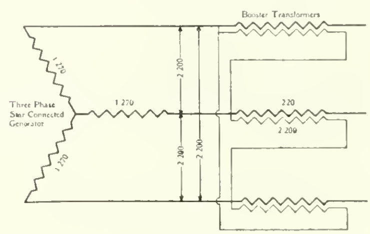


FIG. 23 (b)

connected voltages. Figs. 23 (a, b, c and d) will give an understanding of

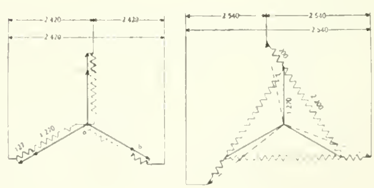


FIG. 23 (c) FIG. 23 (d)

the phase relations of the quantities involved. E. G. R.

24—MOTOR FIELD HEATING—I have a variable speed direct-current shunt motor on a boring mill. This motor gets much warmer when standing than when working under usual conditions. In fact, when it is going to take me several hours to line up a job I open the line switch to avoid overheating the

field coils. Can you explain this to me?

In a variable (or "adjustable") speed motor the increase in speed is caused by a decrease in field strength by the insertion of resistance in the field circuit. In the ordinary controller this resistance is not cut into the field circuit until after the controller handle has been moved beyond the starting notches. Consequently when the controller is in the off position and the line switch is closed the field current is a maximum and the heating likewise a maximum. In a properly designed machine tool controller this can not occur because when the handle is in the off position all of the resistance is inserted in the field circuit, and the field current is a minimum. When the handle is moved to the starting position all of the outside resistance in the field circuit is cut out and the field strength is a maximum, thus giving minimum speed. This condition exists until the second running notch is reached at which point the speed begins to increase, and keeps on increasing as each successive running notch is reached. The ventilation caused by the revolution of the armature is sufficient to carry away the heat generated in the field coils so that they remain cool under all conditions of operation. The installation of a proper controller will allow you to forget about the main line switch and incidentially cut down the power cost of the work done on your particular machine. J. H. K.

25—Does the tangent to the volt-ampere saturation curve of an induction motor taken when running represent correctly the current necessary to force the flux through the air-gap? If not, how should the ampere readings be modified? G. D. B.

Only approximately. At any point the current curve represents the total current necessary for the magnetization of the air-gap and iron and for supplying the losses in the iron and copper as well as those due to friction and windage. The tangent through the origin, therefore, gives too high a value for the magnetizing current corresponding to the air-gap. By calculating the wattless component of the total current, and plotting a new curve near the point of tangency, the tangent to this curve will more nearly represent the gap ampere-turns. However, for practical purposes, the tangent to the original current curve indicates to a sufficient degree of accuracy the gap-ampere turns. I. E. H.

26—Transformers V-Connection—One transformer in a bank of three delta-connected transformers feeding a three-phase circuit is cut out, leaving the other two in V-connection. (a) What formula will give the load on the transformers? (b) How can one determine what load the transformers are carrying?

No formula is necessary as the conditions are really quite simple. The secondary windings of the two transformers are connected together at one end to one wire of the three-phase secondary circuit. The two free ends are connected respectively to the other two circuit wires. Hence the current in the secondary winding of the transformer is the same as that in the circuit wire to which it is connected. This is known if the load is known, or it may be readily measured by an ammeter. If the capacity of the transformer is 100 amperes, the two transformers can deliver 100 amperes to each of the three wires of the secondary circuit.

27—Figuring Meter Capacities—How are the capacities of voltmeters, ammeters, wattmeters, and series transformers determined for a two-phase, 6 600-volt generating station where the total rated capacity of the generators is 900 kw? S. L. S.

The current per phase $= 900\,000 \div (6\,600 \times 2)$ or 68.2 amperes, which allowing for fifty per cent. overload $=$ 102.3 amperes. The nearest standard series transformer has a rating of 100-5 amperes, which is selected. As the standard secondary meter has a five ampere winding it can be used without change. The nearest standard voltage transformer has a ratio of 6 000-100 volts which may be used

for 6 600-volt operation. The standard secondary voltmeter has a 150-volt winding so that when used with a 6 000-100 volt transformer the full scale becomes 6 000÷(100 × 150) or 9 000 volts which is satisfactory. A standard secondary polyphase wattmeter has five ampere, 100-volt windings. When used with a 100-5 series transformer and 6 000-100 voltage transformers, the full scale becomes [(100÷5) × 5] [(6 000÷100) × 100] 2 = 1 200 kw, which is a standard full scale. In this case all the scales are standard, hence no special calibrations are necessary.

28—Ammeter Connections—On a switchboard recently installed for a 2 200 volt, sixty-cycle, three-phase generator, there are three ammeters connected up according to the diagram in Fig. 28 (a). Is this method of connection correct? Will the ammeters register correctly the unbalanced load? J. J. P.

In such an arrangement the transformers on the two lines indicate through their ammeters the currents flowing through them and the current in the third line is the resultant of the other two currents. As connected in Fig. 28 (a) the current through the

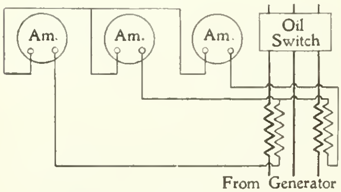


Fig 28 (a)

middle ammeter is the resultant of the currents through the other two, and hence its indications are just the same as though a third transformer was actually used on the middle line. This would not be true for four-wire three-phase systems because the return current in the third wire might not be the same as the resultant of the other two. H. W. B.

29—220 Volt Motor on 440 Volts—What changes are necessary in order to use a four-pole, 220-volt, direct-current motor on a 440-volt circuit beside rewinding the field coils? Can the armature be used without any further changes than removing two brushes and running on the remaining two brushes if the armature is series wound; if it is lap wound? G. K. M.

The result of using a 220-volt motor on a 440-volt circuit would be an increase in speed proportional to the increase in voltage. If the double speed thus obtained is not too excessive to be practicable the change-over could be made. The field coils would not have to be rewound as the field current could be controlled by external resistance. There would be no object in removing two brushes, in fact, the commutation would not be as good as though all four brushes were used. The question of commutation must be considered, for, with the application of a voltage across the commutator bars of twice that for which the motor was designed, excessive sparking is liable to result. With a lap wound armature the short-circuit current of the coils passing under the brushes would be doubled as a result of the increase in speed.

30—In Constant Current Transformers used with self-sustaining mercury vapor rectifiers, why cannot the fixed coils be made the primary instead of the movable coils? H. T. T.

If the secondary coils are movable there is the usual alternating-current magnetic flux causing a repulsion between the primary and secondary coils, but there is also a direct-current magnetic flux between the secondary or movable coils tending to force them apart. This latter flux produces a force which counter-balances that of the alternating-current flux and so destroys the regulation. If the secondary coils are stationary and the primary movable this does not occur and the transformer regulates properly. R. P. J.

THE
ELECTRIC JOURNAL

VOL. V. MARCH, 1908 NO. 3

Detail Engineering

An admirable example of detail engineering is found in the carbon-break circuit breaker. It is customary to consider the man who designs small things as subordinate to the engineer who plans our great undertakings. Such an assumption, however, is not correct when commercial importance is considered. No one would deny praise to the man who designed a steam engine selling for $100 000 and requiring a year to build, especially if it was better than the product of any competitor and earned a fair profit for the builder. At first sight it seems absurd to class along with such a man the engineer who is responsible for a minor piece of apparatus selling for twenty-five dollars, but when it is considered that the sale of a successful device of the latter class will often exceed four thousand per year, it will be seen that in each case the engineer has designed $100 000 worth of product. In each case he works to produce certain results and encounters and solves certain difficulties. An error in judgment which will necessitate the scrapping of one thousand pieces worth ten cents each is as serious an error as one causing the loss of a piston worth one hundred dollars and a saving of ten cents on the smaller design may mean as much in a year as four hundred dollars on the larger.

Under present conditions of competition, patent protection and production, the problem of designing a successful commercial carbon-break circuit breaker is a difficult one. If it is considered that the fundamental type admits of several thousand distinct variations and that the large electric companies can to-day furnish any one of these variations, it is seen that a great number of conditions must be carefully considered.

The successful detail designer must have both the engineering and manufacturing instincts highly developed. The main problems of the best arrangement for each class of work must be given due consideration, but other features relating to cost and production are of great importance from a manufacturing standpoint. These features are not peculiar to any particular apparatus, but have to do broadly with questions of manufacture in quantities and include considerations as apparently remote as the wage system in vogue in a factory

and methods of storing on jobbers' shelves. Circuit breakers are made to sell, and to be successful on the market they must not only be properly designed theoretically, but they must also be planned so that the cost can be kept down. The engineer must, therefore, not only create in his imagination a picture of the circuit breaker in operation, but must also have a preliminary idea of the processes necessary in making the parts, their progress through the factory, their assembly and testing and final shipment to the jobbers and thence to the customers. When working up details of design, he must consider the relative cost of punchings and castings, the safe point to which machining can be reduced, the influence of clearance and adjustment on assembling cost, the effect of wear on the parts, and various other points, the neglect of any one of which may be fatal to the design. He must see that parts needing attention, such as contacts, are accessible and that parts subject to wear are easily replaceable, and must constantly consider the cost.

In the article by Mr. F. W. Harris in this issue of the JOURNAL, the main engineering features of the carbon-break circuit breaker are outlined. The points in design that are touched upon are not all peculiar to this particular device and should therefore be of interest to those who have to do with switching and controlling apparatus of other types. The methods used in solving the circuit breaker problem have been successfully applied to all sorts of kindred devices. These problems have been the subject of a great deal of original thought and invention and the field has been quite thoroughly covered by patents. The field is one in which some very capable men have worked and a great variety of devices have been developed.

Preservation of Natural Resources

Economy in the use of materials and of power are expected in the work of the engineer. It is his recognized duty to design bridges and railroads, locomotives and dynamos with the minimum of material which will secure an adequate result. It is his function to design boilers and engines which will require a minimum of fuel, and to convey and apply power with a minimum of loss.

But in a still larger sense the engineer should prevent waste and destruction and should preserve the natural sources of materials and of power. So vast are the possibilities in this larger field that they merit our best consideration and effort.

The losses by fire in the United States and Canada aggregate $850 000 000 in the past three years. The following interesting comparisons are made by a New York daily: This amount is more than one-third of the cost of the war between Russia and Japan; it is forty percent greater than the net ordinary receipts of the United States in a year; it is as much as has been expended in the United States in three years on its public schools. This waste is in a very large measure unnecessary, it is preventable. To prevent it is a problem as important as the improvement of our waterways or the reform of the currency.

The destruction of our forests, with the consequent scarcity of lumber and its increasing price are generally known but not fully appreciated. It is a crime of modern civilization. We have treated our timber as a child who gathers strawberries by pulling up the plants by the roots. The forest is murdered and a perpetual source of timber is destroyed. More than this, resulting drouths prevent crops, and floods destroy wealth. It is estimated that the floods in the Ohio valley last spring cost $100 000 000. Moreover, soil from forest areas and from fertile plains is washed away. Prof. Swain, of the Massachusetts Institute of Technology appeared at a recent hearing on the Appalachian-White Mountain Forest Reservation bill before the Committee on Agriculture of the House of Representatives. He said:—

"The Society of Civil Engineers has been very conservative and has never before memorialized Congress in any way. The engineers are very apprehensive with reference to the timber supply. They have been trying to find a substitute, and concrete has come into very wide use, but the question of timber is still an exceedingly important one to engineers. We want these forests for the sake of the timber supply and for the regulation of the rivers."

Coal is the basis of modern civilization. Upon it the business of the world depends. It is the source of power. But its supply is limited and the rate of increase in its use is fifty percent in ten years. Even though coal be mined and used economically instead of wastefully; even though engines could be made of perfect efficiency and power be applied with minimum losses, yet the end will come. Why not conserve our fuel by developing other sources of power? An unused water power is an economic waste; energy which might have been usefully used is lost. But if the burning of precious coal instead of using the wasting power of the stream is wrong, what shall we say of the destruction of the water power, and the loss of what

might have been a perpetual source of power? Our grandchildren may wonder at the achievements in which we pride ourselves, but they will marvel at the system of society and government which permits a few individuals for immediate personal profit to destroy the sources of perpetual wealth. The further one considers the waste of our natural resources the more amazing do they appear.

The conditions regarding southern floods were presented to the congressional committee by Mr. W. S. Lee, of the Southern Power Company. Mr. Lee said:—

"We are furnishing power to twenty-six towns, seventy-eight cotton mills and various small manufacturing enterprises. Our work has been going on only six years. In that time we have had to make our plants heavier—that is, sections of dams larger, in order to take care of the enormous floods year after year. These floods are gradually growing, but are followed by low water. In consequence, we are offering three classes of power: The first, calling for twelve months in the year; the second, for eight or ten months only, and the third a still shorter period. We sell for continuous delivery not more than sixty percent of what we ought to have for sale. To maintain a regular supply, we are now designing a two-million-dollar steam plant. We will have to charge for this more costly source of power, and the advantages of cheap power for our customers will, in part, disappear."

Measures are before Congress for acquiring National Forests in the Appalachian and White Mountains. Those who have the matter in charge ask letters, telegrams and memorials urging favorable action to be sent at once to Senators and Representatives, especially the speaker and the chairman of the Committee on Agriculture of the House. Such action will show widespread interest. Information can be secured by asking the Secretary of Agriculture for his Report on the Southern Appalachian and White Mountain Watersheds and the chairman of the House Committee on Agriculture for a Report of the hearing on January 30th.

Chas. F. Scott

Transformer Switching

The magnetizing current in the primary coils of an unloaded transformer causes the coils to attract one another. At the instant of switching the magnetizing currents may be large, but the usual supports and bracing have proven sufficient to withstand all mechanical stresses

due to their action. However, at times of partial or dead short-circuit, with a primary current but slightly greater, transformers after years of service, and others newly installed, have had their coils badly displaced. The indication of the primary ammeter may have been but little less at the instant of switching, yet the reaction between the primary and secondary coils at times of violent overload is often serious, while a correspondingly large magnetizing current does no mechanical harm.

In certain measurements of currents at switching, values of from three to six times full-load were obtained. The normal exciting current was from fifteen to thirty percent of the full-load current, or approximately five percent of the value obtained at switching, from which it appears that the induction was forced well beyond the knee of the magnetization curve. Observation of the potential rises on the transformers gave voltages two to three times normal, when switched either on or off at normal voltages. Lower voltages were tried and still greater rises, in proportion to the impressed voltage, were noted both at times of closing and opening. At five percent of normal voltage twenty times the impressed voltage was observed.

These results indicate that low frequency transformers, which are worked at high induction densities, may be more free from trouble, from this source than higher frequency units, which are worked at lower densities. The excessive potentials developed in the transformer windings at times of switching on or off are frequently dangerously high irrespective of the character of their connected circuits, so that unnecessary or excessive switching is to be avoided.

It has been proposed and confirmed experimentally that a slowly closing switch for moderate voltages, say 10 000 or over, will prevent excessive current rushes to a very considerable degree. When a switch is being closed, the distance between the jaws is reduced until the voltage causes the current to jump across the gap and established a circuit. It is obvious that the spark will jump at or near the point of maximum voltage, that is, at the peak of the voltage wave, which is just what is desired, as is shown in the article on "Current Rushes at Switching," by Mr. J. S. Peck, because practically no excess current is taken under these conditions. In actual practice these same results are approached to a greater or less degree by fairly slow operation of switches.

K. C. Randall

PITTSBURG & BUTLER SINGLE-PHASE RAILWAY

L. H. KIDDER
Superintendent of Motive Power

THE development of heavy interurban electric lines has not been so rapid in western Pennsylvania as in other parts of the state on account of the broken and hilly nature of the country. The first of these roads in the Pittsburg district was built by the Pittsburg & Butler Street Railway Company. This Company's line extends for 38.5 miles north from Pittsburg through a rich farming and oil country and several small towns to Butler, a city of 28 000 inhabitants, containing several large manufacturing industries. As there are two steam roads giving frequent train service between Butler and Pittsburg, it was absolutely necessary that the electric road be first-class in every particular in order to successfully compete with them.

From the center of Pittsburg, the cars run to Etna, a distance of 5.4 miles, over the tracks of the Pittsburg Railways Com-

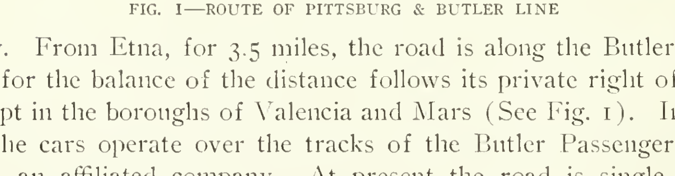


FIG. 1—ROUTE OF PITTSBURG & BUTLER LINE

pany. From Etna, for 3.5 miles, the road is along the Butler Pike, and for the balance of the distance follows its private right of way, except in the boroughs of Valencia and Mars (See Fig. 1). In Butler the cars operate over the tracks of the Butler Passenger Railway, an affiliated company. At present the road is single track, except within the city limits. All steam roads are crossed on overhead steel trestles and grade crossings of the public highways have been eliminated wherever possible. The viaduct over the Baltimore & Ohio Railroad tracks at Bryant is 270 feet long and has a grade of 5.5 percent. The bridge at Butler, crossing the Baltimore & Ohio Railroad and the Bessemer Railroad, contains one girder 115 feet long and has a grade of 5.5 percent. Crossing Thorn Creek and the Bessemer Railroad, near Renfrew, there is a trestle 500 feet long. Grades of from three to six percent are frequent, the heaviest grade

being 9.5 percent. The longest grade averages 5.5 percent for 3 000 feet.

REASONS FOR CHOOSING SINGLE-PHASE ALTERNATING-CURRENT SYSTEM

The problem of obtaining an electrical equipment that would handle heavy cars over these grades at high rates of speed was carefully considered by the Company and its consulting engineers. After a thorough investigation of all the different systems offered, the Westinghouse single-phase alternating-current system was selected as being the most suitable for this installation. In comparing the alternating-current and direct-current systems it was found that with the alternating-current system only two transformer sub-stations, requiring only an occasional inspection, would be necessary. On account of the location of the heavy grades, if direct-current were used, it would be necessary to have at least four rotary converter, or motor-generator set, sub-stations with their usual attendants as well as rotary converter or motor-generator sets at the power house. Only two wires would be required for the alternating-current transmission line, while for a direct-current system three would be required. The cost of the trolley wire would be more with the alternating-current system on account of the catenary suspensions, but this extra cost would be offset by the omission of the heavy feeder wires that would be required with the direct-current system. The power house installation and maintenance would cost practically the same in either case, with the single exception that for the direct-current system rotary-converter or motor-generator sets would have to be added.

THE POWER HOUSE

The power house is located at Renfrew, about six miles from Butler, where a good water supply is available. It is adjacent to the tracks of the Bessemer and the Baltimore & Ohio Railroads, and a spur has been laid from the Baltimore & Ohio Railroad for the supply of coal. The power house, as shown in Fig. 2, is built of pressed brick and is 106 feet wide by 98 feet long by 40 feet high. A brick wall running lengthwise of the building divides it into a boiler and turbine room, 49 feet wide and 52 feet wide, respectively. The building is of fire-proof construction throughout.

Water Supply—The water supply was obtained by building a concrete dam across the Connoquenessing River just below the

outlet of Thorn Creek. The condenser and boiler feed water enters an intake tunnel some distance above the dam, through a settling basin containing movable screens. This tunnel extends under the entire length of the power house. A discharge tunnel parallels the intake tunnel under the power house and to a point near the river, where one branch extends to the stream above, and another to a point below, the dam. Each of these branches is provided with a valve, but the outlet above the dam is used only in case of low water. This latter arrangement provides a cooling basin and allows the same water to be used repeatedly. The feed water, jacket water for the dry vacuum pumps and gland water for the turbines is pumped from the inlet tunnel to a tank above the power house.

FIG. 2—GENERAL VIEW OF POWER HOUSE

Boiler Room Equipment—The original boiler equipment consisted of four 350 hp B. & W. water tube boilers, set in batteries of two boilers each. These boilers are of the double deck style, have four-inch tubes and are designed for a working pressure of 160 pounds. They are provided with superheaters capable of superheating the steam 125 degrees F. The boiler plant has recently been increased by the addition of two 500 hp boilers. Hand firing is used at present, but arrangements have been made for mechanical stokers. Ashes fall from the grates into shutes and are removed by a narrow gauge railway through a tunnel.

The feed water flows from its reservoir through a Bonar vertical open heater to the pumps. Exhaust steam from all pumps and auxiliary engines passes through this heater and raises the temperature of the feed water to 210 degrees F. Duplicate sets of boiler feed water pumps are used, either pump being capable of supplying the entire plant. The feed water pipes are so arranged that each pump can supply one battery or all batteries of boilers. The feed water piping is the only piping in the entire plant that has been duplicated. This has been done to insure against accidents. Each individual boiler is supplied with an automatic feed water regulator.

The boiler gases are conveyed through a flue extending along

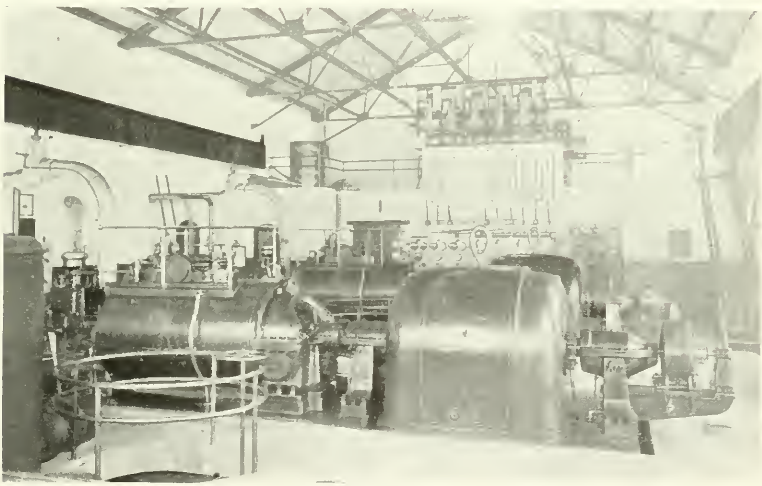


FIG. 3—VIEW SHOWING TURBINES, GENERATORS, EXCITERS, SWITCHBOARD AND HIGH TENSION GALLERY

the rear of the boilers to a stack at the end of the building. This stack is built upon a concrete foundation sixteen feet in diameter by sixteen feet deep. It is constructed of radial hollow tile and stands 125 feet above the breeching. The internal diameter is ten feet six inches at the bottom and nine feet at the top.

Two systems of steam piping are used—one for superheated steam and one for saturated steam. The superheated steam is carried from each boiler through a six-inch heavy steel pipe to a ten-inch header running along the boiler room wall. From this header the steam is conveyed to two 1 000 kw and one 2 000 kw turbines. The saturated steam passes through 2.5-inch pipes to a six-inch

header mounted beside the ten inch superheat header. Provision has been made to connect the saturated and superheated lines together in case of emergency. All auxiliary machinery is operated from the saturated steam header. Live steam lines are connected to the Holly system for the removal of condensed steam.

Turbine Room Equipment—The prime movers, as shown in Fig. 3, consist of two 1 000 kw and one 2 000 kw Westinghouse-Parsons single flow turbines designed for 1 500 r.p.m. at 150 lbs. pressure and 28 inches vacuum. The standard oiling system pro-

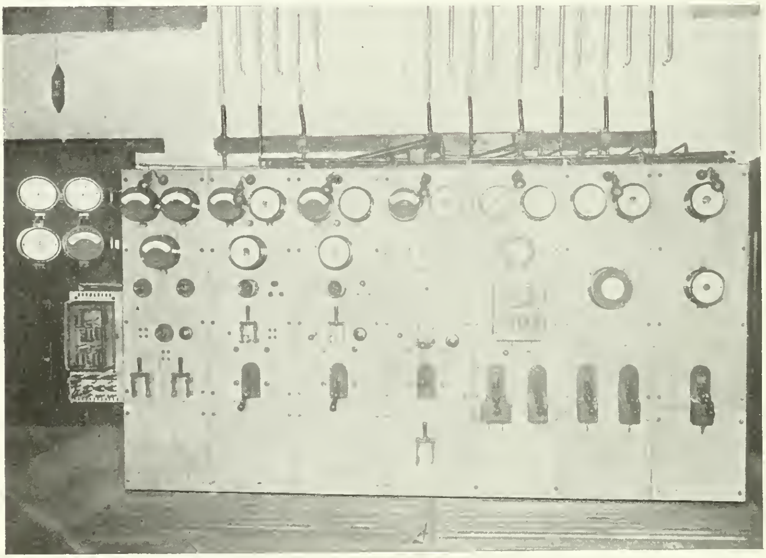


FIG. 4—SWITCHBOARD AT POWER HOUSE

vided with the turbines are connected to a storage tank and a Bonar filtering system. Each turbine is provided with an auxiliary duplex direct-acting steam pump for the supply of oil while starting or stopping, or in case of emergency. Each 1 000 kw turbine is provided with an 18-inch exhaust. This pipe discharges into a 30-inch exhaust pipe, which is fitted with an atmospheric relief valve. When operating non-condensing the exhaust from the turbine may be used in the heater or discharged to atmosphere direct. The 2 000 kw turbine is provided with a 36-inch exhaust pipe. Barometric condensers, made by the Alberger Condenser Company, are used. The condensing water is supplied by centrifugal pumps driven by vertical steam engines. Each condenser is provided with a dry vacuum

pump located on the main turbine floor. With condensing water at a temperature of 70 degrees F, the condensers are capable of maintaining a vacuum of 28 inches. The condensers for the 1 000 kw units have a capacity of 15 000 lbs. of steam per hour, while that for the 2 000 kw unit has a capacity of 30 000 lbs. of steam per hour.

Each turbine is direct-connected to a 3 300-6 600 volt, three-phase, 25 cycle revolving field alternator. These alternators are given a single-phase rating; there being two generators of 750 kw and one of 1 500 kw. The armatures are star-connected. Originally the alternators were connected for 3 300 volts, but they have recently been changed and are now generating 6 600 volts.

FIG. 5—OIL CIRCUIT BREAKERS ON HIGH TENSION GALLERY, OPERATED FROM MAIN SWITCHBOARD

Each alternator is direct-connected to a 125-volt exciter. These exciters are shunt wound and each has a capacity of 35 kw and is capable of exciting both 750 kw alternators. The 1 500 kw unit is provided with a 70 kw exciter capable of providing exciting current for all three alternators.

The switchboard is located at one end of the turbine room, as shown in Fig. 4, and consists of one exciter panel, three generator panels, two transformer feeder panels, and one trolley feeder panel. All feeders from the generator bus-bars are operated by remote hand control oil circuit breakers, shown in Fig. 5, which are located on the high tension gallery.

The transformer room is at the end of the power house, back of the switchboard, and its ceiling forms the floor of the high-tension gallery. The transformer room contains two oil insulated self-

cooling 500 kw and three oil-insulated water-cooled 1 000 kw transformers. The two 500's are connected in open delta, primary and secondary, for the three-phase, 22 000 volt transmission line supplying power to the Butler sub-station. The three 1 000's are connected to single-phase 22 000 volt bus-bars through disconnecting switches. All wiring from the oil circuit breakers is carried along the ceiling of the transformer room on porcelain insulators to the low-tension side of the transformers. In this room there is also a ten kw transformer which steps down the bus-bar voltage to 110 and 220 volts for the station lighting, which is done entirely by incandescent lamps. In the high-tension gallery are mounted enclosed fuse stick type circuit breakers; three on the three-phase transmission line to Butler, and two on the single-phase transmission line feeding the Mars and Bryant transformer sub-stations. Each line is protected by low equivalent lightning arresters and choke coils. In addition to the transmission lines there is a 6 000 volt feeder connected to the trolley line through an oil circuit breaker. As shown in Fig. 6, the outgoing transmission lines pass through terra cotta pipes placed in the wall, inclined downward toward the outside to prevent snow or rain from entering the building.

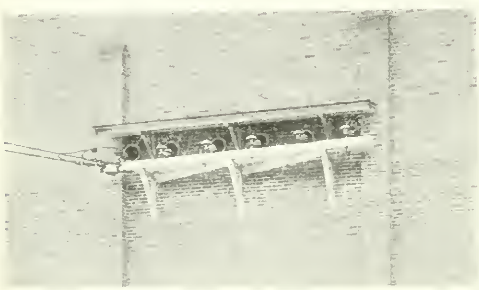


FIG. 6—TRANSMISSION LINES OUTSIDE THE POWER HOUSE

TRANSMISSION LINES

The transmission lines consist of No. 4 copper wire supported on 35 000-volt triple petticoat porcelain insulators fastened to wood cross arms. From a point opposite the power house the transmission lines are carried on the same poles as the trolley wires. The three-phase line extends north a distance of six miles, to the Butler rotary sub-station; while the single-phase line extends south to the Mars transformer sub-station, a distance of sixteen miles. At Mars the transmission line is broken by stick type fused circuit breakers and from there extends to Bryant, a distance of twenty-four miles from the power house. Wherever the transmission line crosses

telephone or telegraph lines a grounded net work of wires is placed between them to prevent accidents. The general arrangement of circuits for the entire system is shown in the diagram of connections in Fig. 7.

SUB-STATIONS

The rotary converter sub-station, located in Butler, contains one bank of three 200 kw and one bank of three 250 kw 22 000 to 340 volt oil insulated transformers; two 500 kw rotary converters and one five-panel switchboard, with the usual instruments. Both banks of transformers are connected to the transmission line through stick type fused circuit breakers. This end of the line is also protected by low equivalent

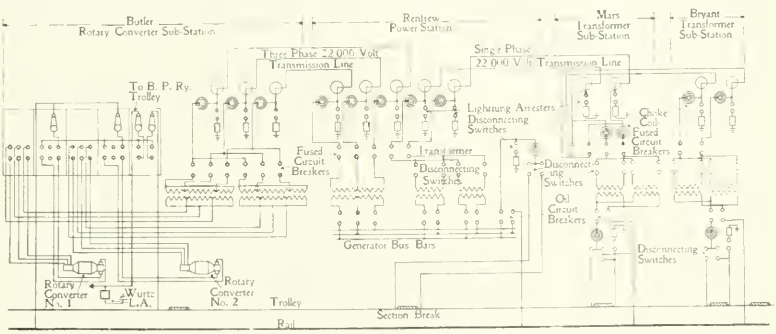


FIG. 7—GENERAL ARRANGEMENT OF CIRCUITS

lightning arresters and choke coils. Each bank of transformers feeds an individual rotary converter. There are two direct-current feeders protected by Wurtz tank lightning arresters. One feeder supplies power for the cars of the Butler Passenger Railway Company and the other supplies the Pittsburg and Butler trolley, which parallels the other trolley in the city of Butler.

In the Mars sub-station there are two 500 kw oil-insulated transformers connected in parellel with disconnecting switches and stick type fused circuit breakers on the high tension side, and an oil circuit breaker on the low tension side. Choke coils and low equivalent lightning arresters are also provided on the high tension lines. The Bryant Station contains a duplicate equipment of the Mars station.

TROLLEY CONSTRUCTION

The trolley construction is of the single catenary type, designed for 6600 volts. On straight track the poles are spaced

120 feet apart. On curves this distance is decreased, the amount depending upon the degree of curvature. On all curves and at various intervals on straight track steady strain insulators are used to keep the trolley wire from swaying and also to keep it directly under the messenger cable. These insulators consist of straight grained pieces of wood impregnated to make them water proof, with malleable iron lugs wedged on either end.

In the boroughs of Mars and Etna poles are placed on either side of the street and the insulators fastened to pieces of T-iron suspended as shown in Fig. 8. At each end of the line, in front of the power house, and at each sub-station are located wooden

FIG. 8—VIEW OF LINE CONSTRUCTION WITH POLES ON EACH SIDE OF STREET

section breaks. These section breaks are made of pieces of treated wood, six feet long, suspended from sleeve type insulators. Spark gap lightning arresters are placed every half mile on the line. A special overhead line construction is used when the trolley passes under low bridges. At such places the messenger cable is made into a dead section by means of a strain insulator on each side of the bridge. Under the bridge two messenger wires are used, forming a triangle with the trolley wire. The messenger cables are supported on sleeve type porcelain insulators fastened to a wooden frame work and the trolley wire is supported by insulating blocks, fastened to the messenger

wires, thus insulating the trolley from the messenger cables and bridge, as shown in Fig. 9.

THE CAR BARNS

The car barns and repair shops are located at Mars, at the middle of the line. This building is of brick, 90 feet wide by 180 feet long. The repair shops are 40 feet wide and are provided with two tracks extending the entire length of the building. The equipment includes all necessary machinery for building new cars and repairing old ones. The machinery is driven by a single-phase induction motor. Also there is a 12 hp triple cylinder gas engine used to drive a direct-current generator for lighting the car barn after the power goes off at night. The car barn contains four tracks with the necessary pits for inspecting and light repair work. In the rear of the barn there is a paint shop and store room. At the front end of the barn there is a store-keeper's office, and directly over this a dispatcher's office.

FIG. 9—VIEW SHOWING OVERHEAD LINE CONSTRUCTION UNDER BRIDGE

The yard wires at the car barns are insulated from the main trolley wire by a section break. A small frame building located about 150 feet from the barns contains the lighting transformer and also an oil circuit breaker to connect the yard wires with the main trolley wires. All yard wires are dead ended at the barns. On account of the high voltage it is necessary to use unusual precautions in the barn to prevent accidents to the workmen. This is done by providing a separate disconnecting switch for each trolley wire in the barn. These switches are enclosed in cases with glass doors, which are kept locked. Each trolley

wire switch is kept open except when power is needed for testing or to move a car.

CARS

At present the car equipment consists of ten passenger cars, and one baggage car built in the Company's shops. The total weight of one car is 40 tons. The under framing of the car was made to a special design to accommodate the single-phase equipment. Five cars are provided with a baggage compartment and all cars are provided with a smoker and lavatory. The cars are finished in mahogany. In addition to incandescent lights at the sides of the cars there are center clusters with holophane globes.

FIG. 10—TWO CAR TRAIN ON THE PITTSBURG & BUTLER LINE

Heating is effected by hot water heaters placed in the smoking compartments. Each car has a copper sheeted roof. All cars are equipped with semi-automatic air brakes. The general appearance of these cars is shown in Fig. 10.

Electrical Equipment of Cars—The motor equipment consists of four 100 hp single-phase motors with a gear ratio of 19 to 64. This gives a maximum speed of 52 miles per hour on level track. These motors are controlled by the alternating-current—direct-current double end multiple unit control system. When operating on alternating-current, current is collected by a pantograph trolley located at the center of the roof. This pantograph is held in contact with the trolley wire at a pressure of from 12 to 15

lbs., by means of two springs located in the pantograph cylinder. The pantograph is lowered by compressed air which acts against these springs. At the bottom of the pantograph shoe are two hooks which engage with the plunger of a small locking cylinder and automatically lock the pantograph when it is lowered. Pantograph control air valves are placed in each vestibule of the car. The usual method of raising the pantograph is, first to admit the air to the large cylinder and thus compress the springs. Air is then admitted to the small cylinder to release the hooks. Then the pantograph is raised gradually by slowly exhausting the air from the large cylinder. The pantograph is insulated from the roof by porcelain sleeve type insulators. From the pantograph, current passes to an automatic oil circuit breaker, which is fitted with no voltage release as well as over load release. It is closed by a lever operated by hand or by the plunger of an air cylinder. A control valve for this air cylinder is placed in each vestibule. From the circuit breaker current passes to a 200 kw 6600 volt, air-blast auto-transformer. From this transformer various leads are taken to the switch groups and the auxiliary apparatus.

A tap giving 198 volts is taken from the transformer for the control circuit. This tap is connected to one of two single-pole, double-throw switches so arranged that the control circuit can be tested on either direct current or alternating current. From the testing switches the control lead is taken to the commutating switch. This switch changes the master controller from the direct-current to the alternating-current switches or vice versa, and is held in the alternating position by means of a magnet whenever there is voltage on the transformer. At all other times it reverts to the direct-current position. The switches for cutting out motors are also located in the commutating switch box. From the commutating switch the various wires of the control circuit go through the master controller and reverser to the unit switches, which are interlocked so that the various switches will close in their proper sequence.

A 284-volt tap is taken from the transformer to the change-over switch, for the pump motor. This switch is located in the front of one vestibule. It is used to change the four field coils of the pump motor from the series to the parallel position and vice versa. When the car is operating on alternating current these coils are in parallel, while on direct current they are all in

series. The change-over switch is hand-operated. The circuit for the transformer blower motor is the only one taken from two inside taps on the transformer. This motor operates at 111 volts.

The light circuit is taken from a 500 volt tap on the transformer. A light relay operated from the change-over switch circuit is used to change from direct current to alternating current. With no voltage on the transformer this relay is in the direct-current position and the lights use the trolley voltage. All lights are arranged in groups of five in series. Two of these circuits also include the two air gage lamps in the vestibules.

When a car is operating on the direct current, the full trolley voltage is always across the control resistance. For the control circuits a tap is taken from this resistance to one of the testing switches, giving 125 volts to ground when all switches are open. As the master controller is changed to different notches new circuits are thrown in parallel with this resistance and consequently the voltage across it drops. When the controller is on the fifth notch there are six parallel circuits, including the resistance, and the voltage has dropped to about 60 volts. For operating on direct current a wheel trolley is placed on each end of the car. An emergency switch is provided so that if the pantograph is disabled the car may be operated from either wheel trolley.

When operating on alternating current, motors *1* and *2*, and *3* and *4* are in series. The two groups are connected in parallel. The master controller has five points, *1*, *3*, and 5 being running positions, and *2* and *4* points where resistance is placed in series with the next higher tap in order to obtain smooth acceleration. The voltage on the running points *1*, *3* and 5 is 260, 370, and 457 volts respectively.

When operating on direct current, the four motors are all in series on all notches of the master controller. On the first four notches grid resistance is used in series with the motors. On the fifth notch all resistance is cut out and the full direct-current voltage is placed across the motors.

In case of an accident a group of two motors may be cut out, either numbers *1* and *2* or numbers *3* and *4*. An individual motor cannot be cut out. When running on direct current with two motors cut out, each motor receives twice its normal operating voltage on the fifth notch of the master controller and almost twice the usual voltage on the other four notches. Also the grid

resistances have to carry larger currents. Cars have been run under these conditions and found to operate very satisfactorily.

TELEPHONE LINE

From Etna to Butler there is a private telephone line consisting of two No. 12 copper wires, transposed every 400 feet to cut down induction. The wires are supported on glass insulators by the trolley poles. Underground conduits are used wherever the pole line crosses from one side to the other. No trouble from noise has been experienced with this line except when it becomes grounded. At each siding there is a telephone booth and a double-pole single-throw switch for connecting the telephone to the line. This switch is so arranged that it is opened when the booth door is closed. Each car is provided with a portable telephone and a jointed pole with suitable contacts for connecting with the telephone wires.

TRAIN DISPATCHING

Trains are operated by dispatchers using the telephone system. Motormen are required to report to dispatchers at all regular meeting points. In case one car is to meet another at a point other than its regular meeting point the dispatcher gives an order to the motorman, who writes it on a regular order blank after which he repeats it to the dispatcher, who OK's it and gives him the time. The order is then read and signed by the conductor. These orders are all turned in to the dispatcher at the end of the day. In case a car is disabled between sidings, the portable telephone is used to notify the dispatcher.

EXPERIENCES AND CONCLUSIONS OBTAINED FROM ONE YEAR'S OPERATION OF THIS ROAD

It is worthy of note that the troubles encountered have been due to defective material and workmanship rather than defective design. In the car equipments recently ordered the only change made in specifications was the substitution of oil-cooled transformers for air blast and a slight modification of the oil circuit breakers.

The power house was placed in operation January 1st, 1907. Cars were run over part of the road soon after this and the reg-

ular schedule was placed in operation over the entire road May 1st, 1907.

In the car wiring several casess of defective joints, caused by poor taping and loose connections, were found. These were due to inexperienced workmen and were overcome by going over the joints and connections in all the cars. No further trouble of this nature has been experienced.

Motors have been subjected to tests with from 50 to 75 percent over-loads in regular service and found to commutate perfectly. There has been no trouble of any kind with commutators or brushes. The commutators have operated 50 000 car miles and as yet do not require turning. There have been but three or four cases of grounded fields and armatures.

During last summer the cars were operated through several severe lightning storms and the only damage sustained was the grounding of the emergency switches on two cars and the burning out of two coils of an auto-transformer on one of the same cars. The line at that time had no lightning arresters except at the power house and sub-stations.

The most serious trouble encountered was with the pantographs and overhead line construction. As there have been a number of different stories told regarding this trouble, an authoritative statement of the case may be of interest. A number of pantographs were put out of commission at the beginning of operation, due to three causes: inexperience of the motormen, shifting of the track and improper alignment of the trolley wire. When the road was started, none of the motormen were familiar with the apparatus and it was but natural to expect them to make some mistakes. The end castings of the pantographs were made of aluminum at first, and several pantographs were damaged, due to these breaking while in service. Brass castings were substituted and this trouble was stopped. In the original alignment of the trolley wire with reference to the track, the wire was allowed to play over the entire shoe. When the wire was near the edge of the shoe, the rolling of the car, due to depression in the track, would allow the shoe to come off the wire. Also, it was found that in building the road, the bracket arms on elevated curves had been placed in a horizontal position instead of parallel with the rails. These bracket arms were changed and the trolley wire restrung so that it would not cover more than ten inches from the center of the shoe at any point on the

line. No further trouble has been experienced since these changes were made.

All the new motormen are required to spend one month's time in the repair shops before they are given charge of a car. Motormen are required to have a sufficient knowledge of the car equipment to enable them to make any minor repairs that may be needed while on the road. For this purpose each motorman is supplied with a tool box and a kit of tools.

There has been but one interruption of the high tension lines. That was due to a defective insulator and was found two days after voltage was placed on the line.

When the road was first put in operation, it was found that the oil circuit breakers at the sub-stations would operate on overloads or short-circuits before the power house circuit breakers. This caused delays in traffic, for in most cases a man had to be sent from some distance to replace the circuit breakers. At present both sub-station low tension oil circuit breakers are plugged in and in addition to this a double fuse is placed in the high tension stick type circuit breakers. With this arrangement and a proper setting of the oil circuit breakers at the power house, it has been found that there is ample protection against short-circuits doing damage to the apparatus. Also service is not interrupted by unnecessary operation of circuit breakers out at a point where there is no attendant.

Where cars pass from the alternating-current to the direct-current trolley wire, the following method has been adopted: First, the pantograph is lowered as the car approaches the end of the catenary line, and the car coasts under the section break and comes to a complete stop. The car is registered in and the motorman sees that the circuit breaker is open and the pantograph locked before the conductor puts up the wheel trolley. In going from the direct-current to the alternating-current trolley wire, the motorman signals the conductor, who pulls down the trolley wheel and fastens it. The car drifts under the section break, the pantograph is raised and the car proceeds without stopping. At each end of the catenary trolley line a switch is provided to turn the power off of a section of the direct-current trolley line, next the section break. This is used in case it is necessary to get on top of the cars for repairs.

Under normal operation, the entire road is connected together electrically, thus placing the secondaries of the transformers at the sub-stations in parallel with the generators. This prevents

the sub-stations from being over-loaded in case of a congestion of cars. The primaries of the transformers in the sub-stations are connected to different taps so as to compensate for the line loss in each case and give full secondary voltage under normal load.

Soon after the road was put in operation, it was found that traffic was much greater than anticipated and it became necessary to order additional equipment. Originally, the two transformer sub-stations contained one 500 kw transformer each and these were fed by two 500 kw transformers in the power house. An additional transformer was placed in the Bryant sub-station soon after the beginning of operation. Recently the two 500 kw transformers in the power house were replaced by three of 1 000 kw capacity. One of the 500 kw transformers was placed in the Mars sub-station and the other is to be placed at Bryant, thus giving the greatest capacity where the load is greatest.

The trolley voltage was 3 300 volts when the road was placed in operation. On account of the grades and traffic being heaviest at the extreme end of the line, it became advisable to change the line voltage from 3 300 to 6 600 volts as originally contemplated. To make this change it was necessary to change the connections of the generator armature coils and the secondaries of all transformers from parallel to series, and recalibrate the switchboard instruments. All power house changes were made in one night. As it was impossible to make the changes in cars and substations the same night, the line voltage was left at 3 300 until later. A direct feeder to the trolley wire at the power house was obtained temporarily by the use of two 1 000 kw transformers. The secondary of one transformer was connected for 6 600 volts. This transformer stepped the voltage up to 22 000, at which voltage it was fed into the second transformer and stepped down to 3 300 volts.

POOR LIGHT COMPLAINTS—A CENTRAL STATION PROBLEM

THE LOGIC OF FREE LAMP RENEWALS

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INVESTIGATION of poor light complaints by engineers and inspectors under my direction and myself in person, for the past ten years resulted in the accumulation of considerable information as to the many different causes, real and imaginary, of dissatisfaction with the lighting service of a central station's customers. As the gravity of this question made itself felt a further analysis was made of the various poor light reports and a record of the findings kept, the general classification of the contributary causes being as follows:

1—Exaggerated idea of the proper illuminating value of the units used by the customer.

2—Unfavorable location of lamps, fixtures and surroundings.

3—Low voltage.

4—Old and inefficient lamps.

Regarding the first case; as a question of good or bad lighting is largely a question of contrast with other illuminants and as opinions differ radically among the various persons engaged in the controversy, this becomes the most difficult matter to discuss and adjust. This point is emphasized by photometer operators who often differ one-half candle on sixteen candle-power lamps and much more than this when different color values enter into consideration. The effectiveness of the light is further dependent upon many different and oftentimes variable conditions, such as the location of the lamps; the character of the surfaces to be lighted; the color and tone of the walls; the general surrounding furniture and decorations; the time of day when compared with daylight, and last, but most important of all, the character of so-called reflectors, which more properly might be called "suppressors"; two examples are shown on Figs. 1 and 2.

The sixteen candle-power lamp has so long been the accepted standard unit for residence lighting that a large majority of electric light users expect as much light or even more from it than from any of the other competitive lights, and as the cost per hour for a sixteen candle 50 watt lamp at ten cents per kw-hr. is about five

mills, as against three mills per hour for a three cubic foot Welsbach lamp rated at 40 to 50 candle-power, it is quite natural for the customer to expect as much for his money.

When intelligently used, and with the assistance of proper reflecting devices and common sense disposition and location of the lamps, incandescent lighting even at an efficiency of 3.1 to 3.5 watts per candle would probably cost no more than gas. The inconvenience of igniting gas often results in allowing it to burn, where electric light would be switched on and off as desired. In addition to the actual cost for gas and renewals of mantles, if one considers the inconveniences and expense caused by the grimy deposit on the ceilings, walls, furniture and decorations in the room, the nuisance and fire risk resulting from constant use of matches, as well as the

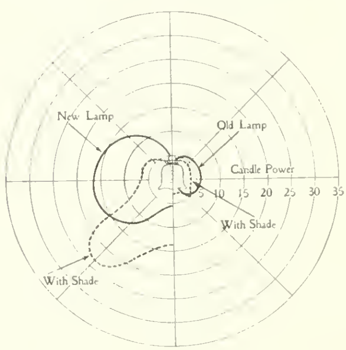

FIG. 1

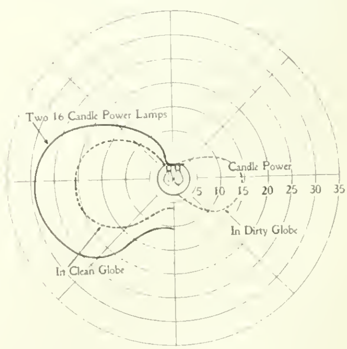

FIG. 2

vitiation of the air in the room, which, for a three cubic foot burner, equals about 30 cubic feet of air per hour, (quite an important factor particularly in winter, at which time the most light is used and least air is admitted by open doors and windows), all the arguments that have enabled the less efficient carbon filament lamp to compete with gas and other illuminants are practically summed up.

In the second case, poorly designed shades and fixtures present a condition that is almost hopeless, as the customer usually resents any criticisms of his fixtures or recommendations for changes. This question has provided the Illuminating Engineering Society with food for discussion for two years, but at the best, the newer installations only are the ones that will be influenced. The most satisfactory results obtained by us were where demonstrations could be made, either by the removal of the offending shades or the relocation of the lamps by use of an extension cord. The fact that

the electric light can be surrounded with cloth and paper shades, has been a great factor in its abuse in this manner, whereas a gas jet would be more apt to set fire to such decorations and tend to prohibit its use. Some effects obtained by the use of the various shades and paper decorations are shown by Fig. 3.

The third case, that of low voltage due to insufficient line copper or capacity of the apparatus installed or the station regulation is comparatively simple of solution by the application of more copper, improved machinery and regulating devices.

The fourth case is that of old and inefficient lamps, which is practically the subject of this paper. From the data collected we become convinced that by far the largest percentage of the troubles was due to the condition of the incandescent lamps themselves, and in order to arrive at some idea of the extent of this evil, our in-

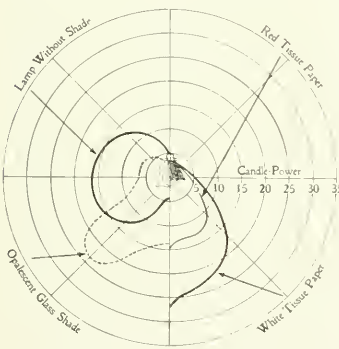

FIG. 3

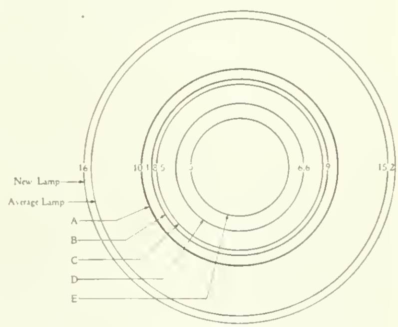

FIG. 4

spectors were instructed to replace one or two lamps that presented the average condition of the customer's lamps by new ones of proper candle-power. The old ones thus obtained were brought to the laboratory and photometered, when some surprising results were obtained.

As the end in view was the free installation and renewal of the lamps by the Company, it was necessary to produce satisfactory evidence that the great outlay involved was justifiable. For this purpose, a hap-hazard collection of 16 candle-power lamps was made from the premises of a number of the better class of our customers. In Fig. 4 some curves are shown giving the horizontal candle-power of some of these lamps, the greatest being 10.1 candle-power and the lowest averages five candle-power. This argument pointed conclusively to the fact that it is not the cost of the lamps that caused the use of old and inefficient units and leads to the question,

"that if this was the condition of the lamps in the homes of men to whom the expense of renewals was an insignificant item, what is the condition of the lamps in the homes of the less well-to-do where the outlay of 15 to 20 cents for an incandescent lamp argued against frequent renewals?"

This condition of affairs is the characteristic tendency of the times for specialization, as we are constantly growing more dependent upon each other and individually concentrating upon one branch of a business, profession or detail of manufacture to the exclusion of all others. The time when we practically produced all our domestic supplies, such as clothes, food, etc., from the raw material to the finished product has been superseded by the time where we expect all the different necessities of life collected, prepared and de-

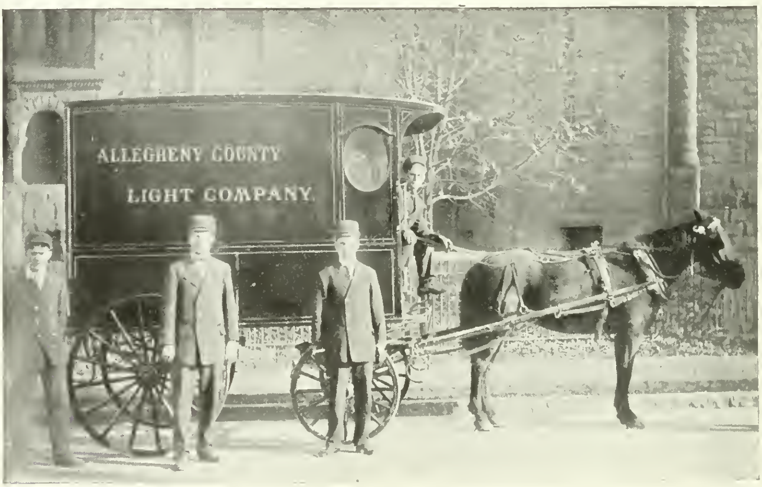

FIG. 5—LAMP RENEWAL WAGON

livered, and almost predigested, as it were, for immediate consumption with the least expenditure of thought and effort on the part of the consumer; and electric lighting service in order to be a competitor of the times, must not only be on hand when the button is pressed, but the candle-power must be maintained without any special investigation or study on the part of the user.

With this in view, it was determined to institute a renewal of the lamps on our customers premises beginning with the residence districts and several definite methods were considered. As the average consumption of energy of a lamp of known candle-power

throughout its useful life is readily calculated, a plan was considered of allowing the subscriber a certain candle-power in lamps for a certain unit of energy. For example, assuming a 50 watt 16 candle-power lamp to have a useful life of 600 hours, one 16 or two eight candle-power lamps would be issued for every 30 kw-hrs. billed. This would make it optional with the customer as to which lamps to renew.

Another plan, followed by lighting companies in other parts of the country, is to provide each customer with a certain percentage

FIG. 6—INTERIOR VIEW OF LAMP RENEWAL WAGON

of his installation in spare lamps, thus enabling him to replace any burned out or unsatisfactory lamps, the old lamps in turn being placed in a box and called for at regular periods by the company's representatives. A number of other cases which are of hardly sufficient importance to describe are in use, but the scheme which was adopted by our Company is substantially as follows:

A wagon, shown in Figs. 5 and 6, was designed for the purpose of holding about 3 000 lamps arranged in accessible racks ac-

cording to their different candle-powers, which would probably give a liberal margin for a day's supply. Carrying trays for the inspectors were provided, who were instructed to remove all lamps from their sockets and replace them with new ones of the same candle-power, with the exception of odd shapes and units above 32 and below eight candle-power. The reason that it was decided to replace all lamps was that, if left to the judgment of the inspector as to which lamps required renewing, we would be apt to land as far away from the point aimed at as we were before, and it was found to take as much time for the inspector to switch on the light and try and select the bad from the good lamps as it would to take

FIG. 7—LAMP INSPECTION DEPARTMENT

out all the lamps, deposit them in one tray and refill the receptacles with new lamps from another tray. The mere placing of clean and polished lamps where the lamps had been dulled and sooty from inattention, in many cases gave satisfactory results.

Preparation was made at the laboratory of this Company to handle these large quantities of lamps; and every new lamp, before being issued to the lamp renewal department for installation, was given a careful test as to candle-power, wattage, spotted filaments, gas, air and a general inspection for cleanliness and mechanical defects. A certain percentage of all new lamps were reserved for life tests and curves showing the performance of each lot as represented by these test lamps are made a matter of record. The entire cost for this is probably 3.5 mills per lamp. All unbroken, returned lamps are inspected by girls (See Fig. 7), who pass them over a white surface and throw aside all bad shaped and blackened

lamps; the lamps that have been passed are turned over to other girls, who first try the lamps for open circuit, then clean and polish the glass, and again pass them over a white surface when any slight discolorations which have not been detected by the first inspector are caught. The lamps, when cleaned and polished, are assorted according to their respective rated candle-powers and voltages, (See Fig. 8), and passed on to the photometering room, where they are measured for candle-power. In this measurement lamps that are found close to the normal rating and within five to seven percent of the efficiency of new lamps of the proper color and bril-

FIG. 8—VIEW IN LAMP TESTING LABORATORY

A—Lamps on life test.
B—Switchboard.
C—Assorted sample lamps in paper bags ready for test.
D—Tested lamps in trays.
E—Photometer room.

liancy are issued to the lamp renewal department for reinstallation. The cost for this operation is about five mills per reclaimed lamp.

In the first renewal very few lamps that could be reclaimed were found, but on later renewals a larger percentage of the lamps brought in are expected to be in candle-power and efficiency (when cleaned and polished) in good condition for service, as it is a matter of fact that many lamps in out-of-the-way places are rarely, if ever, used, but the customer, however, bases his complaint of poor light on probably ten percent and less of his total installation; where the lamps are the ones most constantly used and are correspondingly more nearly burned out, as the greater majority of customers

will not even change the lamps about in the fixtures. This further emphasizes their disinclination to spend any time or thought on this matter.

The method of carrying out this work appeared simple enough until numerous little details in connection therewith were taken into consideration, the principal difficulty being the great variety of receptacles met with, and the different voltages in use. As we restricted ourselves to lamps of candle-power from eight to 32 inclusive, the next step was to standardize receptacles. This meant the use of an adapter, which was both expensive and tedious to install. This adapter is a threaded shell provided with two steel prongs projecting from the upper end of the shell at diametrical opposite points and when pressed firmly home in Westinghouse receptacles, engages the fibre insulation, thus holding it in place, and provides the screw receptacle for the Edison base lamp. A similar adapter was used on T-H and other receptacles, but in more limited amounts. At this point we encountered another difficulty in the form of defective recetacles and poorly wired fixtures, causing short-circuits and open or grounded circuits when the adapters were installed. Of course it did not matter how long the trouble existed previous to the visit of our inspectors, as we were usually held responsible for the results, and after a very few cases, decided to make the repairs immediately. The amount of this kind of work was astonishing. However, it was considered good policy to make these repairs in order to avoid all possible occasions for misunderstanding with our subscribers, and again all lamps that were put in commission represented that much probable additional revenue in time to come. Another difficulty met with which was happily rare, was the breakage of glassware by the inspectors in extracting lamps or placing adapters while making repairs to the fixtures.

The standardization of voltage was a more serious matter, but for several years previous to the adoption of free lamp renewals, an effort was made to standardize our voltage in order to enable us to take advantage of party transformer distribution, as well as to simplify the apparatus required, and it, therefore, meant only the concentration of our efforts on the districts in which the lamp renewals were first to be made.

The average man, from past experiences, is more or less suspicious of anything that is offered for nothing, and the experience of gas companies, who attempted to improve the lighting by a gratuitous installation of improved gas tips, was that they were

promptly accused by the majority of the customers of attempting to increase the flow of gas, so it was deemed advisable to anticipate the visit of our inspectors by a circular letter explaining the object of this move; stating that every lamp installed was tested as to candle-power, energy consumption, etc., thus protecting the customer's interests at no cost to them. However, this did not allay suspicion and usually required a few succeeding month's bills to convince the customer of the bona-fide intentions of the Company. The conditions of the lamps found, which too often were purchased at bargain sales, were of a candle-power fifty percent more or less (principally less) than rated, and with an energy consumption from ten to thirty percent more or less, (principally more) than given and adapted for voltages which were usually from 104 to 110 volts. As the greatest demand for incandescent lamps is for those of 104 and 110-volt rating, and as the manufacture of incandescent lamps is by no means an exact science, the result is that there are a great number of lamps that fall to either side of the two just mentioned, and it was found that if an intermediate voltage should be decided upon, an excellent selection could be obtained; accordingly 108 volts was selected as the rating of the lamps to be installed and the regulation of the circuits adjusted accordingly.

The cost for doing this work is as yet somwhat indefinite. Using as a basis a lamp of 3.5 watts per candle-power, with an average economical or useful life of about 800 hours, consuming, during this period of service, 45 kw-hrs., we have a renewal cost of four mills per kw-hr. On the basis, however, of a lamp of 3.1 initial watts per candle-power, with an economical life of 550 hours and energy consumption of about 27 kw-hrs., the renewals cost about 6.5 mills per kw-hr. Inasmuch, however, as the lamps are handled for inspection and testing several times before the breaking point is reached, the cost per kw-hr. will run somewhat higher than the figures given above.

An entirely new situation has been presented by the advent of the high efficiency metallic filament lamps, and while this Company has increased the efficiency of their lamps supplied, by the adoption of the 3.1 over the 3.5 watts per candle-power lamps, it is very questionable whether electric lighting companies will be able to afford free renewals of units, which will cost 100 percent more for the same candle-power with one-third the energy consumption and consequently one-third the revenue.

CURRENT RUSHES AT SWITCHING

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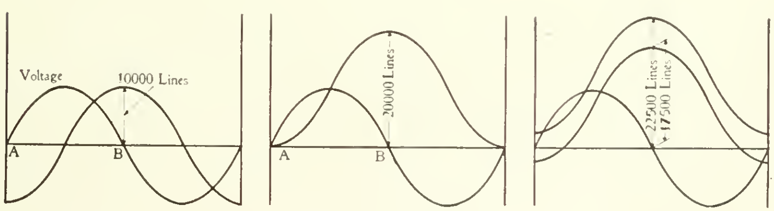
IT has long been known that when transformers are switched on to a circuit, there are at times very heavy rushes of current which are sufficient to open circuit breakers, although the circuit breakers may be set for a current much in excess of the full-load value. In testing rooms it is quite customary to hold the circuit breaker in by hand for a few seconds after switching on a transformer. The explanation of the phenomena is quite simple, though it does not appear to be generally understood and is usually put down in an indefinite way to residual magnetism. As long as transformers were made for high frequency circuits only, rushes of current at switching were practically unknown, and did not become noticeable until lower frequencies, i. e., 25 to 33, came into general use. This was due to the fact that on high frequency circuits, transformers were seldom worked at inductions higher than 6 000 c.g.s. lines per sq.cm., while on 25 cycles inductions of twice this value were adopted.

In a transformer working on open circuit, it may be assumed that the voltage wave is of sine form, and that the flux wave is of similar form, lagging behind the voltage wave by 90 degrees, as shown in Fig. 1, where the maximum value of the flux is taken at 10 000 lines. On open circuits, the counter-electromotive force is practically equal to the impressed electromotive force, and it may be assumed that the voltage curve shown is produced by the flux wave. To produce the voltage wave from *A* to *B*, Fig. 1, it is necessary that the flux pass from 10 000 negative to 10 000 positive, which is equivalent to a change of 20 000 lines, or the wave from *A* to *B* could be produced by the same shape of flux curve starting from zero and reaching a maximum of 20 000 lines.

If it is assumed that the transformer has no residual magnetism and is suddenly switched on the circuit at the point *A* of the voltage wave, Fig. 2, i. e., at zero potential, it is evident that the flux wave must start at point *A* and reach a maximum of 20 000 lines in order to produce the voltage wave between points *A* and *B*, and since the voltage wave is the same as in Fig. 1, the flux wave must have exactly the same shape but will be moved above the zero line. At the maximum induction the iron will be very highly saturated

and a heavy magnetizing current will flow. Obviously the higher the induction at which the iron is worked under normal conditions, the greater will be the saturation and the greater the rush of current at the instant of switching. If the switch is closed at the maximum point of the voltage wave, the flux will start at zero and go through its cycle without exceeding the normal induction and without excess current, as in Fig. 1. If the switch is closed when the voltage is between zero and its maximum value, the maximum induction will be higher than when the switch is closed at the maximum point, but lower than when it is closed at the zero point of the voltage wave. If the iron is already magnetized when the switch is closed, the maximum flux may be greater or less than if the iron was not magnetized, depending on the direction of the original magnetization. If in Fig. 3 all conditions are the same as in Fig. 2, except that the iron is already magnetized 2 500 lines in the positive direction, the flux wave, instead of starting at zero, will start at a value 2 500



FIGS. 1, 2 AND 3

above zero, and reach a maximum of 22 500. If, however, the iron is magnetized 2 500 lines in the negative direction, the maximum flux would be only 17 500.

It has been assumed that the only voltages in the system are the impressed and the counter-e.m.f.'s, but there is also an ohmic drop, the tendency of which is to reduce the maximum value of the flux and to change it from pulsating to an alternating one, and to bring it quickly to its normal value. It is evident that under the conditions shown in Fig. 2 without ohmic drop, the flux wave would continue to pulsate from zero to 20 000 lines, although the voltage wave would be alternating. On account of the ohmic drop, the counter e.m.f. will be reduced and the flux will not reach the maximum value shown in Fig. 2, but will fall below this. With each voltage alternation the maximum value of the flux is reduced, and in a very short time it will reach its normal position with equal positive and negative values. Any drop in the circuit feeding the transformer will, of course, reduce the maximum value of the flux.

From the above it is evident that the maximum flux value obtainable is somewhat less than double the normal, unless there is some residual magnetism, in which event it may be greater or less than twice the normal, also that this maximum is obtained only when the switch is closed at the zero point of the voltage wave. The maximum current which will flow will depend on the permeability of the iron at the high induction and on the ohmic resistance of the windings.

With three-phase transformers the same phenomena occurs, one phase reaching a higher induction than either of the others. For example, if the switch is closed when one phase is at the zero point of the voltage curve, the other phases will have equal voltages, but opposite in direction, and the flux variations will be as shown in Fig 4, from which it may be seen that the flux in one phase of

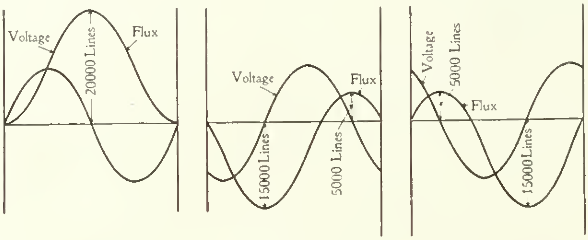


FIG. 4

the transformer reaches twice the normal value and in each of the other one and one-half times the normal value, but at all times the resultant of the three flux values is zero. Since the induction is higher in one phase than in the others, and as the permeability is different with different inductions, the current in this phase will be greater than the resultant of that in the other two. With a delta-delta or delta-star connection there is nothing to prevent this unbalancing in current, but with a star-star connection the current in one phase cannot be greater than the resultant of the other two, so that the voltage on this phase drops and that on the other two rises until the proper relation of currents is obtained. In other words, the star point is no longer the neutral, as the neutral is shifted away from the transformer working at the highest induction. With a star-delta connection, the neutral point remains fixed, but currents circulate within the closed delta and so equalize the currents on the star-connected side. Thus with a delta connection on either winding, the conditions are much the same as with a single-phase

transformer, while, with the star connection, the current rush is somewhat reduced.

With induction motor-generator sets it is quite common practice to bring the set up to speed from the direct-current end, then to switch full voltage on the motor. In this case there will be an action in the motor similar to that which occurs in a three-phase transformer and a heavy rush of current will occur.

The writer's attention was recently called to the action of an induction motor whose dimensions were very small for its output, indicating that it was worked at a very high induction. When started, the motor was brought to its proper no-load speed, then switched on the circuit. As soon as the switch was closed, there was a heavy rush of current, and the whole machine vibrated violently. Of course a rush of current would be obtained if the motor was not at the proper speed when the switch was closed, but care was taken to see that the speed was right, and other motors on the same circuit, presumably worked at lower induction, did not show this excessive vibration.

Improvements in methods of ventilation and the introduction of alloyed steel with its low losses make it possible to work at much higher induction than was thought possible a few years ago, and as permeabilities have not been increased materially, it appears that modern apparatus is more subject to rushes of current at switching than is that of older design. There has been little or no trouble traceable to this current rush at the time of switching, and it has been mainly objectionable on account of the occasional opening of a circuit breaker. There are, however, two sources of danger: First, to the system, and second, to the apparatus. The danger to the system is that the heavy current rush may set up surges which produce high voltages on certain parts of the system. On some systems there is also likely to be a sudden drop in voltage at the time of switching, which may give an objectionable wink in lights. The principal danger to the apparatus is that the coils may be distorted or given severe shocks, which often repeated may do serious damage.

THE PROTECTION OF ELECTRIC CIRCUITS AND APPARATUS FROM LIGHTNING AND SIMILAR DISTURBANCES (Cont.)

R. P. JACKSON

CABLE PROTECTION

THE use of a resistance to ground the neutral of a system is necessary only to prevent an excessive rise of current before the armature reaction of the generators has had time to take effect, in case of accidental grounding of one phase of the system. The amount of this resistance will vary with the voltage and capacity of the station and in general should have such a value as to just permit the tripping of the highest set circuit breaker on the system. Such excessive rise of current introduces severe mechanical stresses on the generators, transformers and cables.

The use of choke coils for protecting cables is not to be recommended for the reason that choke coils possess considerable inductance while cables have in general but little inductance, but high electrostatic capacity. The combination of inductance and capacity in series is liable to produce a condition of resonance in which a greater potential may appear over each than over both in series as these two potentials may be nearly opposite in phase.

SELECTION OF PROTECTIVE APPARATUS

Since the protection afforded in any case is directly proportional to the difference in resistance to static discharges offered by the lightning arrester from that offered by the apparatus it is intended to shield, preference should be given to devices that have the lowest equivalent spark gap, which should always be considerably lower than that of the apparatus to be protected. By equivalent spark gap is meant that definite form of gap which, when placed in multiple with the arrester, just fails to take the discharge. The length of this gap is the measure of the freedom of discharge of an arrester.

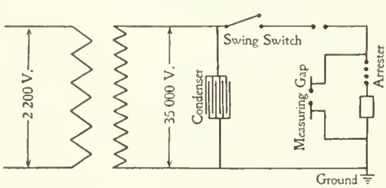


FIG. 5—METHOD OF MEASURING EQUIVALENT SPARK GAP

Fig. 5 indicates a suitable method of measuring this equivalent spark gap. The condenser is added to give volume to the spark and the little gap in series with the swing switch breaks down when the

switch is closed and adds to the suddenness of the wave striking the arrester. This condenser may be readily made up of plates of glass and sheets of tinfoil interleaved in the usual manner. The measuring gap is capable of adjustment until the spark just passes to it instead of through the arrester. The length of this gap gives a comparative measure of the effectiveness of various arresters. This length, however, is not suitable for an absolute measurement, as it will vary greatly, depending on the shape of the tap terminals.

FIG. 6—MULTI-PATH TYPE OF LIGHTNING ARRESTER

In new apparatus the resistance offered to the passage of static disturbance enables it to be protected with comparative ease; but after apparatus has been in service a long time, especially if it has been overheated or otherwise abused, the relative protection offered by lightning arresters becomes lower and lower until a point is finally reached where the insulation of the apparatus is so poor as to afford a far better discharge path than that of the protective devices themselves. This relation has long been recognized, but perhaps is not generally understood. The most recent designs of lightning arresters possess equivalent gaps about as low as is likely to be obtained by any reliable self-restoring devices. By this is meant devices which do not have to be reset after each discharge.

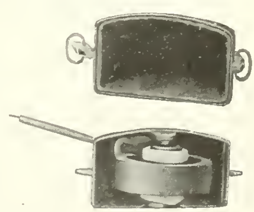


FIG. 7—MULTI-PATH LIGHTNING ARRESTER

Interior view showing the discharge block in place.

GENERAL CONSIDERATIONS

In order to maintain the maximum protection with a minimum expenditure for appliances and maintenance, it is essential when laying out plans for a protective equipment to keep the following fundamental considerations in view:

1—The location of stations, lines and apparatus should be definitely determined before the equipment is selected.

2—The style and character of the plant must be considered, since these affect the nature of the protection employed. General practice under this head is divided into two classes:

Low tension distribution for alternating and direct currents.

High tension alternating-current power transmission.

LOW TENSION DISTRIBUTION

The class of lightning arresters used for low tension distribution circuits includes protective apparatus for secondary distribution systems of alternating-current lighting and railway plants and for systems operating direct-current apparatus. The distribution of a large number of lightning arresters along a trolley line is desirable for many reasons. Experience has demonstrated that lightning shows a tendency to take the nearest and shortest path to earth that it can find even though it be of a somewhat high resistance. By placing arresters every 1 000 feet, or closer where storms are very severe, the discharges are offered numerous paths to earth without endangering the machinery. On long, exposed interurban lines, it is almost impossible to have too many arresters; for the larger the number, the greater is the assurance that each will do its work, that no arrester will be overloaded, and that there will be no excess discharge to go through the insulation.

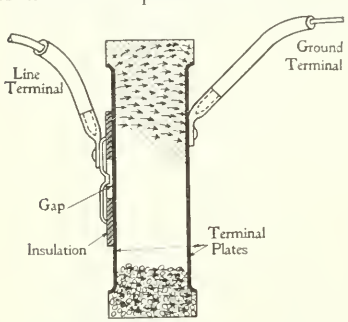


FIG. 8—OPERATION OF MULTI-PATH BLOCK UNDER DISCHARGE

Inspection—The number of lightning and railway plants that are using lightning arresters with leads burned off and grounds poorly made indicates that the question of lightning protection is given indifferent attention, thus injuring the operation and throwing most unjust criticism on the manufacturers of protective apparatus. These lax conditions could be remedied at small cost, by each lighting and railway plant employing a man whose special duty it should be to map out the system, locate arresters and see that they are in first class condition, see that the ground connections are well made, and report regularly to the manager after each storm, the damage done. This procedure has been tried in some of the most progressive systems, and the results obtained indicate so conclusively the value of close observation of the performance of protective apparatus that no enterprising railway or lighting company can afford to neglect this phase of its engineering activity.

MULTI-PATH LIGHTNING ARRESTER

The multipath lightning arrester, as shown in Figs. 6, 7 and 8, is single-pole and is suitable for either alternating-current or direct-

current circuits at any voltage up to 1 000. This type of arrester has been produced by a special method of development tests; it has an indefinite length of life and offers a desirable freedom of discharge. The name multi-path is derived from the fact that the static discharge spreads itself over a carborundum block along a number of minute discharge paths. The nominal voltage between the line and the ground is subdivided between so many minute gaps that the voltage across each gap is too small to maintain an arc after a high voltage discharge has passed. (See Fig. 8.) The action is analogous to that of a coherer in wireless telegraphy, in that the body of the block becomes momentarily conducting as a result of the shock given the slightly separated particles. Thus, while the ohmic resistance to slowly applied low potentials is several megohms, the equivalent spark gap is very low. To ascertain whether a given arrester is still intact and in good condition, apply the leads of a voltmeter to the terminals of the arrester; if full voltage is indicated the arrester is intact and in service. After considerable service, say 2 000 discharges, the arrester will probably break down and fuse off one of its leads.

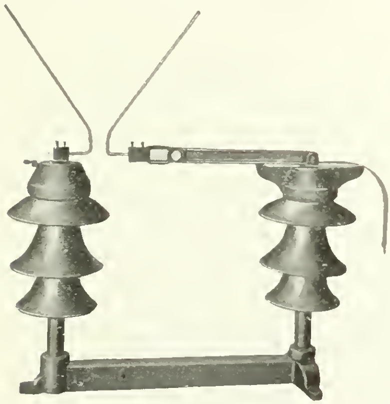


FIG. 9—COMBINATION OF HORN GAP AND DISCONNECTING SWITCH

ELECTROLYTIC LIGHTNING ARRESTER*

Engineers have been experimenting for a number of years with a film that forms on aluminum plates when treated in certain electrolytes. This film is very thin, being comparable in thickness to a wave length of light; the electrostatic capacity of a condenser of which this film is the dielectric is, therefore, very great. If the e.m.f. is continuous, only leakage current passes through the film; but with an alternating e.m.f. a leakage and a charging, or condenser, current are superimposed. It was discovered that this film has a very high apparent resistance when moderate voltages are impressed upon it, a very desirable characteristic for lightning arrester purposes; but when the voltage reaches a higher value, the film

*See article on "The Electrolytic Lightning Arrester," August, 1907, p. 469.

breaks down in myriads of minute punctures, making almost a short-circuit for these higher voltages. As soon, however, as the pressure is reduced again the minute punctures seal up at once, and the original high resistance reasserts itself. For electrical pressure this action is exactly the same as that of a safety valve on a boiler. The efforts made to develop this device into suitable shape for protective purposes have resulted in the various types of electrolytic arresters.

ALUMINUM PLATES

For convenience of mounting, the aluminum plates used in the electrolytic lightning arresters, are pressed into a tray form, so that when set one within another (separated by small insulating washers) these trays may be built into a column capable of withstanding high

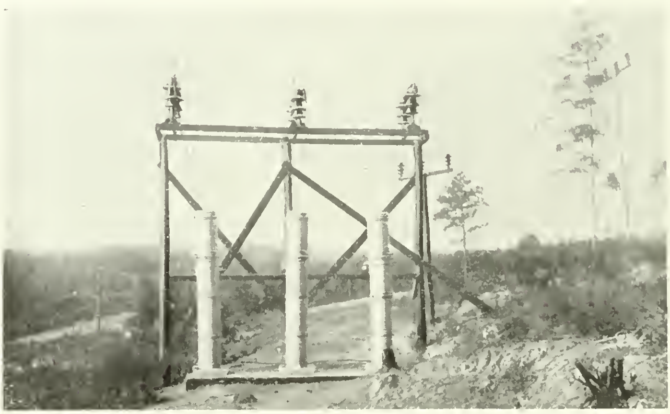


FIG. 10—ELECTROLYTIC LIGHTNING ARRESTER INSTALLED ON THE TRANSMISSION LINES OF THE SOUTHERN POWER COMPANY

voltages and still retaining the safety valve characteristics of a single plate. There are two sizes of columns, viz., one suitable for voltages between 4 000 and 7 500, and the other for voltages between 7 500 and 13 500. The columns are enclosed in stone ware jars, which may be mounted one upon another to form arresters for any desired voltage. Each unit when placed in the pan at the bottom, or on another unit, automatically makes contact.

THE ELECTROLYTE

The electrolyte is dissolved in pure water, preferably distilled, and is poured into the top of the arrester unit. When the first tray is full, the electrolyte runs over into the second, then overflows into the third and so on until all are full, when the surplus escapes

through a hole in the bottom of the stoneware containing-jar to the next jar below it, if there is one, or if not into the pan at the bottom. Since the electrolyte fills only the trays and not the jar, there being a clearance between the trays and the walls of the jar, there is no opportunity for current to pass through the arrester except from tray to tray through the electrolyte. To prevent continued evaporation the jar should be allowed to stand a few days until some of the solution in the trays has evaporated and then sufficient transformer oil should be poured in to fill the trays. This requires about one pint of

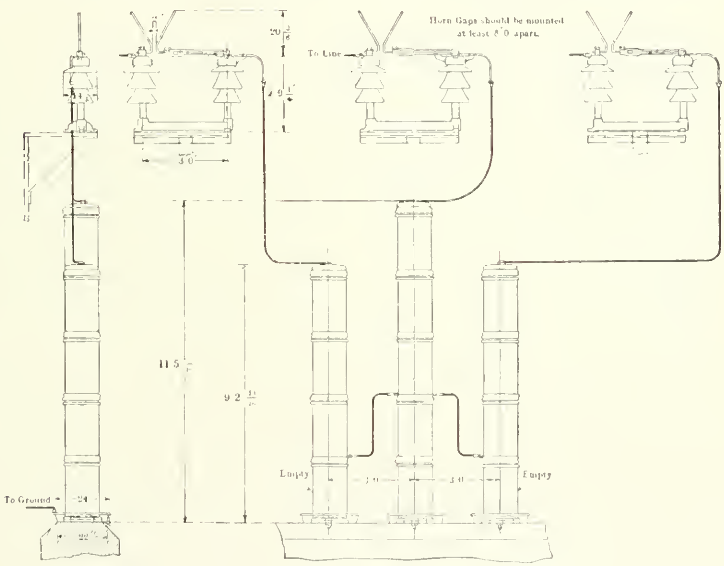


FIG. 11—ELECTROLYTIC LIGHTNING ARRESTERS
Outline for three-phase installation.

oil per jar. The film of oil thus formed over the water prevents practically all further evaporation. In the side of each containing-jar is placed a small slot for purposes of inspection. This slot is covered by a lid that may be pushed to one side and trays inspected to determine their condition and the amount of electrolyte and oil in them.

Gaps—It is necessary, of course, to have on the line side of these electrolytic elements a gap that will withstand the normal voltage of the system, but that will break down with over-voltage and permit the surge to discharge through the electrolytic units. For voltages lower than 13 500 volts, the gap is between the usual non-arcing

metal cylinders, which easily suppress the small current (about one ampere at 13 500 volts) that follows a discharge. For voltages higher than 13 500 there is used a "horn" type of gap with sufficient arc-suppressing power to disrupt the current that flows through the electrolytic unit after a lightning discharge has passed. It is not advisable to use a horn gap for less than 13 500 volts, since the gap is so small that the arc will not rise properly, and consequently the horn feature is no longer useful. The gap of a horn arrester may be combined with a disconnecting switch in such a way that the gap element forms the blade of the switch; thus, when the gap element is swung open as a switch blade, the lightning arrester is disconnected from the line, as shown in Fig. 9.

Voltages—Electrolytic arresters are made for all voltages from 4 000 up to almost any practical voltage. For alternating-current circuits there is a marked difference in the lightning arrester equipment on circuits having grounded neutrals from those which have not. For instance, a single-phase or a two-phase circuit of 10 000 volts having no grounded neutral must have lightning arresters capable of sustaining a power pressure of 10 000 volts; since if one leg of the circuit becomes grounded, the other is subjected to a strain of 10 000 volts. If, however, the center of the transformer winding, or the neutral, were grounded, there could be no normal or power stress of more than 5 000 volts. Consequently an arrester capable of maintaining itself under a 5 000-volt stress would be sufficient.

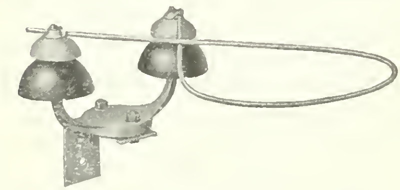


FIG. 12—INSULATED SUPPORTING LOOP

For use with electrolytic lightning arresters when mounted in columns of three or more.

Likewise on an underground three-phase circuit of 10 000 volts, each arrester will have to be designed for 10 000 volts. If the circuit, however, is star-connected, and the center of the star grounded, the arrester need be for only 58 percent of the operating voltage, or 5 800 volts. On ungrounded three-phase circuits three units may be installed and interconnected so as to reduce the total size and cost of the arresters. In Figs. 10 and 11 are shown an actual installation and outline sketch of a three-phase installation.

Outdoor and Indoor Service—Both the gap and the electrolytic unit may be installed either indoors or out. While the electrolyte will freeze at about 28 degrees F., it is not permanently damaged by

freezing, yet when in frozen condition its conductivity is comparatively low, and the protective power of the arrester is correspondingly decreased; hence in order to obtain the best results during periods of low temperature, the electrolyte should not be allowed to freeze. For outdoor mounting it is necessary to support the columns against wind pressure or other disturbances tending to overturn them. An insulated support has been designed for this purpose for use whenever three or more jars or units are placed in the same column. These supports consist of U-shaped castings tipped with heavy insulators and mounted on iron brackets which are bolted securely to poles placed on each side of the column of units. On the tops of the insulators are fastened iron insulator caps to which are clamped the arms, or loop, that supports the column of units and holds it firmly in its proper position, as shown in Fig. 12.

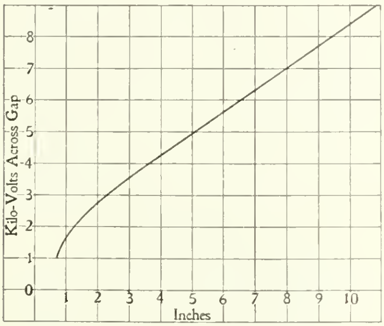


FIG. 13—SPARK GAP CURVE

Horn-Gap Setting—By means of the curve shown in Fig. 13 the proper lengths for horn gaps may be determined. As already stated, horn gaps should not be used on potentials lower than 13 500 volts, since the gap for lower voltages is so small that the arc will not rise properly and break. Some latitude is allowable in the setting of the horn gaps. The distance between the horns should be as short as possible without causing the small arc to strike back and rise again repeatedly. Normally the arc will rise but a foot or so on the higher voltages. The power current being very small, the arc is not at all vicious or flaming.

(*To be continued.*)

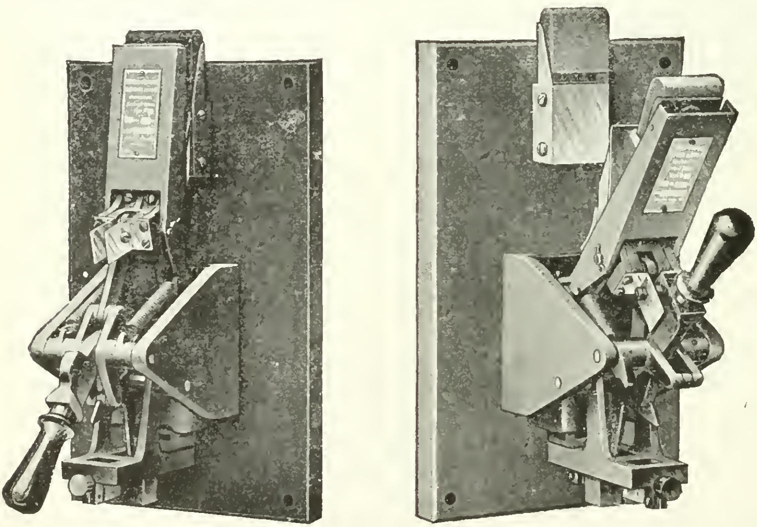
CIRCUIT-INTERRUPTING DEVICES—V

CARBON-BREAK CIRCUIT BREAKERS

F. W. HARRIS

PRESENT designs of carbon-break circuit breakers include capacities of 15 000 amperes at 750 volts for both direct and alternating-current circuits. This type of circuit breaker takes its name from the fact that the final opening or arc takes place on carbon blocks. The carbon contact is necessarily accompanied by a main laminated contact of copper, and all commercial circuit breakers of this type include such features.

For general purposes they must be capable of assembly in either the one, two, three or four-pole form and must be made in all the



FIGS. 1 AND 2

varieties for over-load, under-load, over-voltage, under-voltage, etc., that are called for commercially.

DETAILS OF DESIGN

Carbons—The current normally carried by the main copper contacts is shifted to the carbon contacts when the circuit breaker is opening, the final arcing taking place on them. As carbon has a high resistance and will not pit or weld under the action of an arc, the circuit may be repeatedly opened without injury. The carbon

brushes should be of sufficient size to be strong mechanically and should be so arranged that they project beyond other parts in opening, so that all arcing will take place between them. One carbon is commonly secured rigidly above the upper stationary contact, the other being mounted on a pivot held on the moving arm by means of a spring. This pivoting of the carbon causes it to break the surface on the under side. A form shown in Fig. 3 uses carbons which make a sliding sidewise contact. This arrangement has not been used in any but the smaller sizes and is probably not as good as the standard method. Carbon contacts should be readily renewable, although under conditions of actual service, such renewals are very rarely needed. Most circuit breakers do not open heavy short-circuits except at long intervals, many never, and are used simply to interrupt the circuits under ordinary conditions.

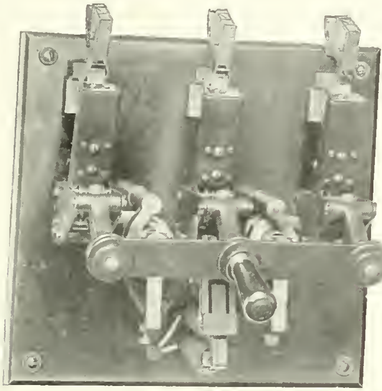


FIG. 3

Carbon Arm—The carbons may be carried on flat strips of copper or phosphor bronze, the spring of this strip being depended upon to insure contact. Such a circuit breaker is shown in Fig. 4. Inasmuch as failure of the carbon contacts to relieve the copper contacts of the final breaking of the arcs will very quickly ruin a circuit breaker, a better method consists in using a solid carbon arm. This is pivoted on the moving arm and carries at its upper end the moving carbon, itself pivoted, and at its lower end a tension spring which holds the carbons in firm contact when the circuit breaker is closed. When the circuit breaker opens this contact is maintained until the main brush has opened. The carbon arm then starts to open and snaps out the arc by its quick action. In the large types of circuit breakers, the carbon arm, when started, moves with a much greater angular velocity

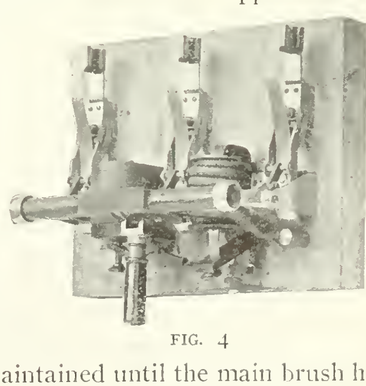


FIG. 4

than the main arm (see Fig. 5). Such action is, of course, impossible with flat spring construction, which is furthermore liable to be bent when handled and to destruction by overheating.

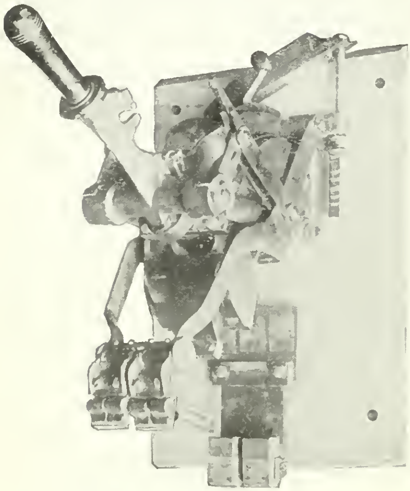


FIG. 5

Main Contacts — As the carbon contacts have a very high resistance, the current must be carried by the main contacts when the circuit breaker is closed. These are generally of laminated form, being made of thin leaves of spring copper, the edges of which are pressed against solid copper blocks when the circuit breaker is closed, this construction giving a multiplicity of bearing points between contacts. Experiments prove that there is less contact resistance per unit of area between a number of flat contacts of small area than between a single contact of large area. For this reason laminated brushes are used, and, as commonly constructed, the brush in closing is caused to slide across the solid contact, thus making good contact. To be successful, however, this type of circuit breaker should be worked at high pressure and be maintained at that pressure even after considerable use. The drop in milli-volts and the deflection of the center of the brush for different pressures for two forms of carbon circuit breaker brushes, are plotted in Fig. 6. With

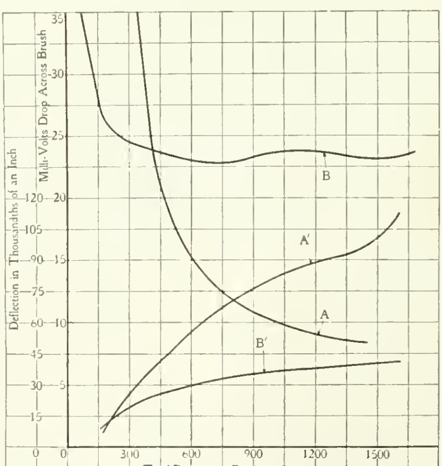


FIG. 6

brush *A* a pressure of 1 200 lbs. total gives a drop of nine milli-volts *(Curve A)* and a deflection at the center of the brush

of 0.087 inches *(Curve A')*. Brush *B* at the same pressure gives a drop of 23.5 milli-volts (Curve *B*) and a deflection of 0.039 inches (Curve *B'*). These curves show in a striking way the superiority of brush *A*, as heating at the contacts is directly proportional to the drop, and the deflection of the brush is a measure of its ability to carry current as the parts wear. In circuit breakers which are closed down against a latch or stop, this flexibility is most necessary. It would probably be preferable to regulate this pressure by an auxiliary steel spring, but this feature has never been successfully incorporated in such designs.

Laminated brushes are made either to span a pair of stationary contact blocks or simply to make contact in one block, the current being carried from the moving element by a flexible shunt. The latter type is practicable only in smaller circuit breakers such as shown in Fig. 7, as with those for more than a few hundred amperes, the shunts become expensive and difficult of construction.

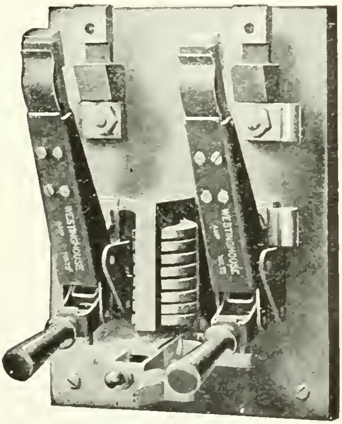


FIG. 7—TWO-POLE CIRCUIT-BREAKER, OPEN

In some specifications a requirement of 200 amperes per square inch of brush surface is called for. Such a requirement shows a lack of knowledge regarding such brushes. In Fig. 6, brush *A* carried 440 amperes per per square inch while brush *B* could carry only 200. It is extremely likely that two surfaces pressed together with pressures approximately equal to their strength in compression, would show a capacity about equal to a solid bar, and it is an established fact that laminated brush areas are dependent on pressures, so that any specification of area without a corresponding statement regarding pressure is meaningless. The specification of temperature rise covers this point and should be satisfactory. The laminated brush has, however, certain inherent defects which it is probable will in time cause it to be abandoned wherever possible. It is necessarily expensive, as it is made of expensive material with considerable labor, and furthermore, it is easily destroyed by overheating. Brush copper is given its spring temper by rolling many times without annealing. If it is annealed the temper is immediately destroyed. In

practice a poor contact on a brush will start overheating, which becomes cumulative, due to the rapid annealing, which immediately starts, and the consequent falling off of pressure. This destroys a valuable part of the circuit breaker whose replacement is expensive. Especially in industrial work is this true, for here circuit breakers do not receive the attention that is usually given them on switchboards and on this account oil circuit breakers with solid contacts are better devices for such service.

Nuts and Terminals—Circuit breakers are provided with clamping nuts and terminals arranged to be soldered to the cable or wire leads before being clamped in place. (See Fig. 8.) There is no excuse for any other sort of connection being used on such apparatus, as these terminals are now made in the smaller sizes from copper pipe by simply flattening the end and punching a hole, and are available at a nominal cost.

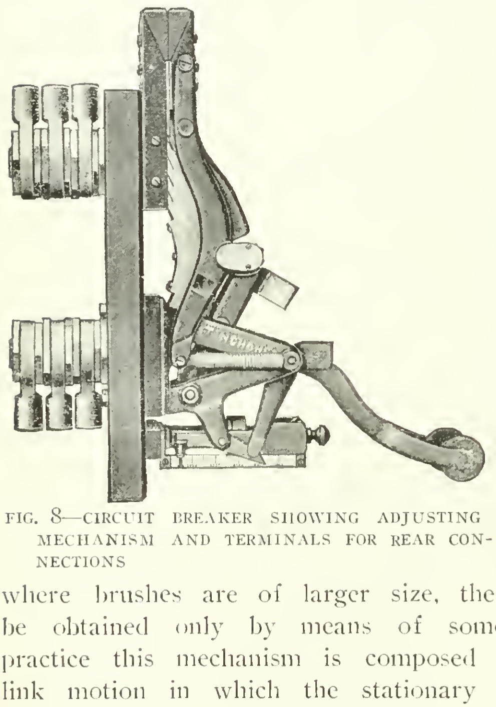
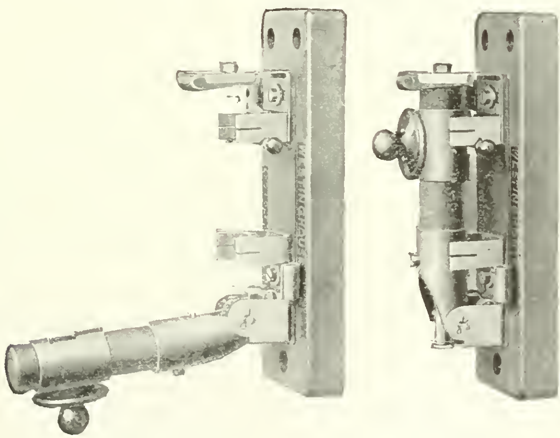


FIG. 8—CIRCUIT BREAKER SHOWING ADJUSTING MECHANISM AND TERMINALS FOR REAR CONNECTIONS

Mechanism — In all the standard types the brush is carried on a swinging arm. In smaller circuit breakers, such as shown in Figs. 9 and 10, this arm may be closed directly, but where brushes are of larger size, the necessary pressure can be obtained only by means of some link mechanism. In practice this mechanism is composed of some form of four-link motion in which the stationary frame forms one link, the moving arm another and the toggle links complete the four, these links providing the necessary increase in leverage. An examination of various commercial designs shows three general types: First, those in which pressure is applied directly to the brush arm, which is held in by a latch, as in Figs. 9 and 10; second, four-link mechanisms in which the toggle passes the center and thus holds the circuit breaker closed, as in Fig. 7, and third, four-link mechanisms in which the toggle does not pass the center, but is held

in by a latch, as in Fig. 5. The last type only is applicable to the larger sizes of circuit breakers, giving, as it does, high brush pressures with quick opening and low latch pressure, since it requires less time and power to open a latch than to break a toggle.

Coils and Calibrations—All circuit breakers are primarily overload devices, that is, they operate when the current of the circuit exceeds a set value. Any other functions are usually secondary in their nature, although special circuit breakers are very often made without any overload features whatever. The range of circuit breakers is usually eighty to 160 percent of the rated current and this current is varied by changing the coil or varying the weights on the armature. In designing a "line" of circuit breakers, a few main



FIGS. 9 AND 10—FRONT CONNECTED CIRCUIT BREAKER, OPEN AND CLOSED

sizes are selected, and frames, mechanism, etc., are designed for these, intermediate sizes being produced by changing the coils. In a circuit breaker of 1 000 amperes and over, no coil is necessary, as the main current, in passing through the circuit breaker, passes around a magnetic circuit and the one turn at 1 000 amperes gives the necessary 1 000 ampere turns. Circuit breakers of lower capacity have two general forms of tripping coils, which may be designated as solenoid and magnetic types. In the former, as, for example, in Fig. 11, a core is drawn up into a coil; in the second an ordinary magnet is used, its armature being hinged. In either case the movement of the core or armature either breaks the toggle or trips the latch, thus opening the circuit breaker. In some commer-

cial forms the armature is carried on a small scale beam with a sliding weight to vary the resistance to magnetic pull, the air gap being maintained constant. In other circuit-breakers, such as that shown in Fig. 5, the weight to be lifted is maintained constant, the air-gap being varied. In some types, springs are substituted for weights and have proven quite satisfactory if the spring is well made and not worked at a point where it will be strained.

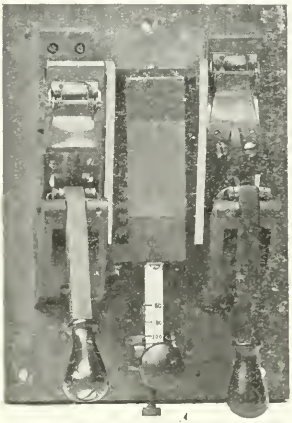


FIG. 11

Bases and Barriers—In most cases circuit breakers are mounted on slate, soapstone or marble bases and, where the poles are close together, barriers are provided to prevent arcing between them, as illustrated in Fig. 11. The barriers may be of the same material as the base or of wood, fiber, asbestos lumber or similar material.

Handles and Cross-bars—There seems to be no material superior to well dried and treated wood for these parts. The handles usually have a durable black finish and a polished ferrule, but the cross-bars are left dull black. Cross-bars are usually required between multipolar circuit breaker levers to cause them to close together, and are also used between the latches or the tripping mechanism to cause them to open together.

(*To be continued.*)

PROTECTIVE RELAYS (Cont.)

ALTERNATING-CURRENT OVERLOAD RELAYS—SINGLE AND POLYPHASE

M. C. RYPINSKI

INSTANTANEOUS ACTION

This type of relay is used for alternating-current circuits where it is desired to obtain protection only at the limiting capacity of the apparatus. This type of relay is made in both single and polyphase forms, one form of the latter being shown in Fig. 17. The action of this relay is instantaneous, but it may be used in combination with an auxiliary time limit relay to give time element tripping. In principle, this relay is similar to the Kelvin type voltmeters and ammeters except that its moving system is mounted in pivoted bearings and carries a set of contacts to which the tripping current is led by a spiral spring. The polyphase form involves two sets of single-phase elements. The construction of the polyphase form of relay is shown in detail in Fig. 18.

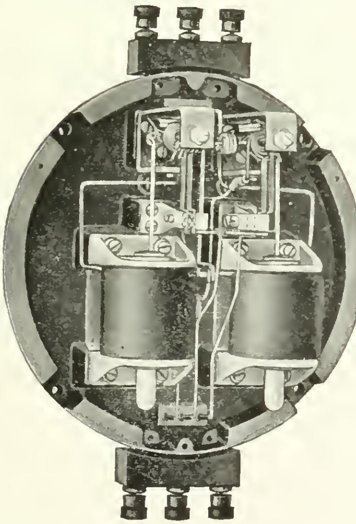


FIG. 17 — POLYPHASE ALTERNATING-CURRENT OVERLOAD RELAY—INSTANTANEOUS ACTION

Normally, the relay stands with its contacts open, the core being lighter than its counter-balancing weights *M* and *O*. Upon current being applied to the coil *A*, the latter magnetizes and attracts the core *B*, tending to draw it down. When the current in *A* becomes sufficient to overcome the counter-balancing effect of *M* and *O* the core *B* descends and closes the contacts *J-J* and *K-K*, thereby energizing the trip coil of the breaker and opening the circuit. The function of the damping oil in the tube *F* is to prevent external or internal vibration from causing uncertain vibratory contacts, sparking, etc., and to prevent sudden surges from operating the relay. The use of a heavy oil will give the relay an inverse time element action, but such a time element is not entirely reliable except under favorable conditions, owing to the variation in oil density caused by changes in temperature.

The terminals at the top and bottom of the case carry current into the coils and contacts respectively. The single-phase relay has two upper or coil terminals and three lower or contact terminals.

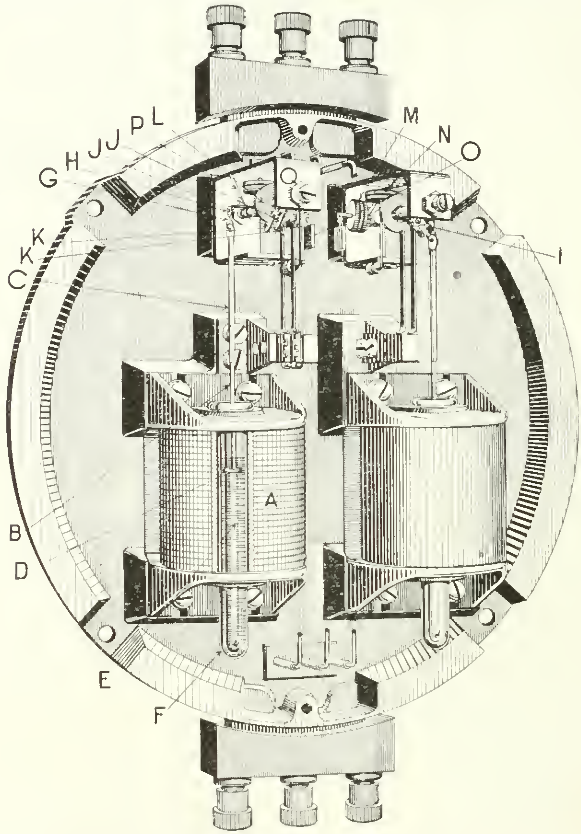


FIG. 18—CONSTRUCTION DETAILS OF RELAY SHOWN IN FIG. 17

A is a solenoid wound for five amperes.

B is a soft iron core supported by a brass sleeve *C* and terminating at the lower end in a piston *D*. The lower portion of the core *B* as well as the piston *D* are below the surface of the coil *E* in the glass tube *F*. The coil *A* is shown cut away to show the internal arrangement of the core and tube.

F rests upon the upper supporting bracket of *A*. The sleeve *C* is flattened at its upper end and drilled to fit over the hook *G*.

G is attached to an arm *H* extending from the pivoted shaft *I* to which is attached also the moving contacts *J-J* (engaging stationary contacts *K-K*), the spiral spring conductor *L*, adjustable weights *M* and *N* and the replaceable weight *O*. An arm *P* attached to shaft *I* and arranged to bear against the supporting bracket *O* limits the upward movement of the system.

The three contact terminals provide for closing the two independent tripping circuits. Where only one tripping circuit exists, the two

outside contact terminals are connected together and used in connection with the middle terminal. The polyphase relay has three upper or coil terminals and three lower or contact terminals. The coils in the two elements of this relay are connected with one lead in common to the middle of the three coil terminals and with the other leads connected to the corresponding outer terminals. The contact terminals of the single-phase relay are similarly arranged to those of the polyphase relay shown in Fig. 18.

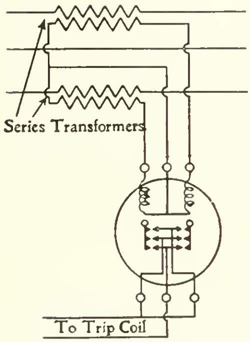


FIG. 19
CONNECTION DIAGRAM
Two-phase relay with single trip circuit.

As relays of this type are wound for only five amperes, they require series transformers on all circuits of greater normal capacity. In protecting a single-phase circuit one series transformer of suitable capacity and one single-phase relay of suitable frequency will be required. For a two-phase circuit two series transformers and a polyphase relay will be required, connected as shown in Fig. 19. For a three-phase circuit three series transformers and a polyphase relay of suitable frequency will be required, connected as in Fig. 20. Two transformers are not sufficient for the protection of a three-phase circuit as the third phase is thus left unprotected from short-circuits to ground.

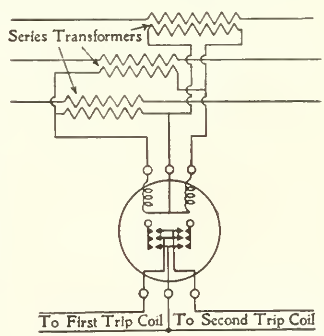


FIG. 20—CONNECTION DIAGRAM
Three-phase relay with two trip circuits; transformers connected in "Z."

The three transformers used must be connected in "Z," i. e., similar to a delta connection with the "common" transformer reversed as indicated in Fig. 20. There is an advantage in using this connection over that of the straight delta, as in the latter each element of the relay receives current which is the resultant of the curernts in the two transformers to which it is directly connected, thus, if each transformer has five amperes flowing, the resultant will be 8.66 amperes. An overload on one phase only will, therefore, affect the relay less than an overload on two or more phases. If, however, the series transformer, which is common to the two elements of the relay is reversed at its terminals, the "Z" connection is

obtained. The five ampere currents in the series transformers will now combine to form a five ampere current in the relay coils instead of an 8.66 ampere current. It is desired that the relay shall act when the current in any of the individual phases reaches a certain value, independent of the currents in the other phases. Obviously the relay should not act when the currents in each of the phases is materially lower than the tripping value, even though the vector sum of two of the phases may be greater. The "Z" connection secures this condition as the effect of an overload on one phase only is nearly the same as an overload on all phases. Thus, the relay action is determined by the maximum current in any one phase rather than the sum of the currents in the different phases. Transformers connected in "Z" do not, however, give the proper phase relation in the resultant circuits for the operation of wattmeters or similar apparatus into which the phase relation of current to voltage enters.

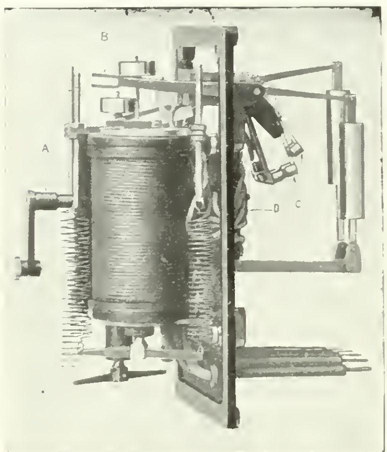


FIG. 21—POLYPHASE ALTERNATING-CURRENT RELAY—DEFINITE TIME ELEMENT ACTION

With a given line current at which tripping is desired, the relay current per element is determined by dividing the line current by the ratio of the series transformers. This holds good for either the single, two or three-phase applications.

DEFINITE TIME ELEMENT ACTION

This type of relay is used for the overload protection of feeders, etc., where it is desired to maintain operation for a predetermined length of time independent of the overload condition. This relay is used mainly in the polyphase form, shown with cover removed, in Fig. 21, involving two single-phase elements each consisting of a solenoid, core and a contact system. The solenoid draws up the core, thereby relieving the contact system of sufficient counterbalancing weight to allow it to close. The closing action is restrained by an air dash pot which limits the closure to a definite time after

the system is relieved of its counterbalancing weight. Shunt trip contacts are provided arranged for operating two tripping circuits, but where only one tripping circuit exists, the two outer contact terminals may be connected together.

Two series transformers connected in "V" are required for each relay for use on three or four-wire two-phase circuits. For three or four wire three-phase circuits three series transformers connected in "Z" are required for each relay as shown in Fig. 22.

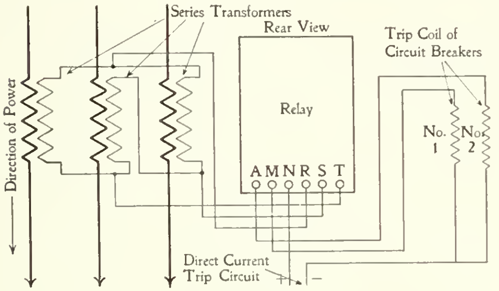


FIG. 22—CONNECTION DIAGRAM

Three-phase overload relay—definite time element action, with two trip circuits and transformers connected in "Z."

The range of the overload adjustment is four to eight amperes, being varied by an index lever extending through the front of the case and traveling over a graduated scale. This index lever acts by cutting coil turns into and out of the circuit.

The range of the time element adjustment is from one to five seconds and is varied by means of an index lever extending through the side of the relay case and traveling over a graduated scale. This lever acts by varying the distance through which the contacts have to travel before they meet.

(*To be continued.*)

EXPERIENCE ON THE ROAD

AN EMERGENCY TRANSFORMER CONNECTION

M. C. GODBE, Electrical Engineer
Salt Lake City, Utah

At the concentrating mill of the Boston Consolidated Mining Company of this city, where some 4 000 kilowatts in transformers, designed for 88 000 volts primary and 460 volts secondary, and 3 000 hp in motors are being installed, it became necessary to furnish temporary service to some 2 300 volt and 460 volt three-phase motors from a 4 000 volt four-wire three-phase line. It was very important that power be furnished to these motors before the sub-station and permanent service was complete. Three 250 kw, 2 300 to 460 volt transformers, which were to be used to step up from our switchboard voltage of 460 volts to 2 300 volts for some motors operating a mile from the sub-station, were available and these were temporarily connected, as shown in Fig. 1, to the 4 000 volt line from which we were allowed to take a maximum of 300 kw. The primaries of transformers *A* and *B* were connected to the neutral and lines *1* and *2*. The secondaries of these transformers were connected in "V" for 460 volts by reversing the secondary of one transformer. For the 2 300 volt service three-phase power was obtained by connecting the neutral and line *3* for one phase. The low-tension side of transformer *B* was used to excite *C*, the primary of which was connected as shown to give the proper three-phase relation with the phase from neutral to *3*. Satisfactory service was furnished in this manner and no trouble was experienced. The voltages on the 2 300 volt motors were not perfectly balanced at full-load, but were not enough out of balance to give the slightest trouble.

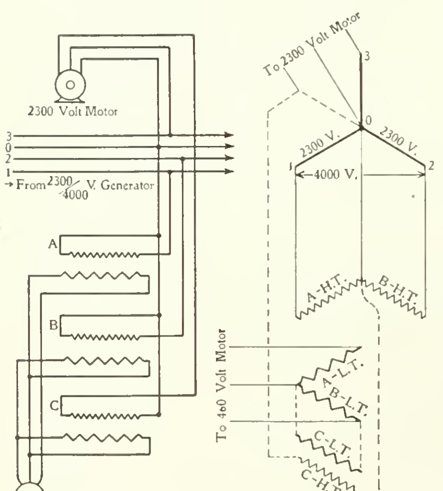


FIG. 1

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

31—Nature of Current in Balancing Coils—What is the character of the resulting current which flows in the leads from the balancing coils to the armature of a three-wire, direct-current generator when the generator is unbalanced.

G. D. B.

The resulting current would be a slightly pulsating direct-current, the resultant of the direct-current flowing in the neutral wire and the magnetizing current of the balancing coils. The magnetizing current of the balancing coils is of very small magnitude and consequently the pulsations are of such small magnitude as to be imperceptible on a volt-meter connected across this part of the circuit. Investigation by means of the oscillograph shows the slightly pulsating character of the current. W. M. D.

32—Undercutting Mica on Commutators—What is the object in undercutting the mica as is sometimes done on the commutators of railway motors?

G. D. B.

To prevent "high mica." There are two distinct actions that affect the commutator surface of a railway motor; first, a burning of the copper due to sparking, and second, a scouring action of the brushes on the commutator, which wears down the mica as well as the copper, and which takes place whenever the motor is running. The scouring action is usually sufficient to keep the mica worn down even with the copper, provided a soft grade of mica is used for the commutator strips. In the case of single-phase motors and some large direct-current motors without commutating poles, the ratio of the scouring action to the burning action may not be great enough to prevent high mica. This is due, in part at least, to sparking caused, in the case of single-phase motors, by the reversal of primary flux through the short-circuited coil at the moment of commutation, and in the case of large direct-current motors, by the high reactance of the armature coils.

Commutating poles have the effect of preventing sparking and, for this reason, it is unnecessary to undercut the mica on the commutators of large direct-current motors with commutating poles. H. C. K.

33—Efficiencies of Motors. Kindly give some figures on the comparative efficiencies of industrial motors. What actual efficiencies may be expected of standard alternating-current motors of say, 1, 5, 10, 50, and 100 hp capacity and how do these efficiencies compare with those of direct-current motors for the same service? W. O. M.

The average efficiencies that may be expected of alternating-current sixty-cycle motors and direct-current motors are as follows:

	60 Cycle Motors		Direct-current Motors
hp.	Efficiency	Poles	Efficiency
1	77	4	77
5	84	4	86
10	85	6	85
50	87	8	90
100	90	12	92

These efficiencies are for standard speed motors. The speeds of the direct-current machines are approximately the same as those of the 60-cycle motors. In motors of large size for 25-cycles the efficiencies would be the same as those for the 60 cycles, but for sizes from one to ten hp the efficiencies would be from one to two percent lower, since the speed of the 25-cycle motors is about 720 r.p.m. as compared with 1 700 r.p.m. for the 60-cycle motors. C. W. D.

34—Motor Drive for Woodworking Machinery. Are alternating-current or direct-current motors better adapted for driving woodworking machinery? Why? T. E. R. B.

Alternating-current motors are bet-

ter adapted for driving woodworking machinery on account of their simplicity and decreased fire risk as compared with direct-current motors. Practically all woodworking machinery is of the constant speed type and runs at a relatively high speed, consequently the induction motor is especially well adapted. In woodworking plants the dust collects over everything and unless direct-current motors are boxed in or are of the wholly enclosed type there is a very considerable fire risk. Since there are no moving contacts on induction motors, this risk is not present. The operation of woodworking machinery is extremely intermittent and the loads are of an extremely variable character, varying from ten percent of the capacity of the motor to 100 or 150 percent., consequently a type of motor should be selected which will carry large overloads and here again the induction motor is especially applicable. C. R.

35—A 40 hp, two-phase, sixty-cycle, 1 100 volt, 850 r.p.m. motor is working on a two-phase, 133 cycle, 1 200-volt circuit. On an auto-starter panel are two auto-transformers each marked 75 to 100 hp, 2 000 volts, sixty cycle, two-phase. Please explain the operation of this combination and give diagram of connections including transformers. Why 2 000-volt transformers? This motor will not start with load but must be started first, then the load thrown on, after which operation is satisfactory. Why is this? Is this the best arrangement for this frequency? T. E. D.

This particular combination using a 60-cycle, 2 000-volt auto-transformer with a 1 200-volt, 133-cycle motor was probably made for commercial reasons only. The 133 cycle, 1 200-volt transformer is probably not a standard piece of apparatus, while the 60-cycle, 2 000-volt transformer is a standard size. In order to use the 2 000-volt transformer, however, it is necessary to select a transformer having a hp rating twice as large as that of the motor, because the current at the lower voltage is twice what it is at the higher voltage. In this way, by taking the larger sized transformer at the higher voltage, the same current carrying capacity is obtained as in the smaller transformer at the lower voltage. The question of frequency takes care of itself, since it is always permissible to raise the frequency on any transformer. A diagram could not be furnished without knowledge as to the kind of starter used; the following connections, however, are made on the starter: One side of the auto-transformer is permanently connected to one wire of one phase of the line. In the starting position, the starter connects the other side of the transformer to the other side of the line and connects the motor to one side of the line and to the tap on this transformer. In the running position, the starter connects the motor directly to the line. Regarding the question of starting, this depends only on the motor and upon the initial voltage which is impressed on it. The starter cannot be held responsible for good or bad starting if it performs this function of supplying the motor with a particular voltage. This combination is seemingly as satisfactory as any which could be made. If the auto-transformers had been designed for this particular service, however, less material could have been used to produce a transformer which would be just as satisfactory. In other words, the transformer has a great deal more iron in its magnetic circuit and consequently more copper than is necessary, and the magnetizing current taken by this transformer is very low. E. E. L.

36—Series Transformers. It is said that if the secondary circuit of a current transformer is left open while the current is flowing through the primary, the apparatus will burn out. I have witnessed a current transformer with the secondary open while the primary current was on with no such injurious effect. Will you kindly explain what causes such a phenomenon? Is it due to a high e.m.f. induced in the secondary winding? Also, does the ratio of the number of turns in the secondary to the number of turns in the primary equal the ratio of the secondary voltage to the primary

voltage (drop across the primary winding), as is the case with the potential transformer? T. L. W.

The exciting current of a series transformer is the element which causes the ratio of primary and secondary currents to be slightly different from the ratio of the primary and secondary turns. To minimize this error in the ratio, the magnetic density in the core is kept very low in the design. When the demagnetizing effect of the secondary winding is not present, i. e., when the secondary circuit is open, the density runs up to many times the normal and the iron loss becomes large. Whether the transformer burns out or not depends upon whether or not it has enough surface to radiate the heat developed. The ratio of the drop across the primary to the secondary voltage developed, (including that necessary for secondary resistance drop) is the same as the ratio of primary to secondary turns. W. D.

37—Is The Inductance of a Coil greater or less with a closed magnetic circuit? Why? H. M. M.

A closed magnetic circuit has a much higher density for a given number of exciting ampere-turns, than one consisting partly of an air path, since its reluctance is much decreased by the increased permeability of the magnetic material. The inductance of a coil is directly proportional to the number of lines of force enclosed. The inductance of a coil with a closed magnetic circuit is therefore the greater. W. D.

38—Transformers in Multiple Is there any reason why a bank of three transformers connected in "delta" on both high and low tension sides cannot be operated in multiple with three transformers connected in "star" on a three-phase circuit, assuming, of course, the two sets of transformers give the same voltage at their terminals? Can transformers in "V" be operated in multiple with three transformers in delta, also in star? R. F. H.

Consider six similar single-phase transformers of the same polarity, i. e., which give secondary voltages having the same relation to the primary voltage. If three of these transformers be connected delta-delta, they may be paralleled with the three remaining units connected star-star; provided the terminal voltages of the two groups is the same. It is of course impossible to parallel a group of transformers connected either delta-star or star-delta with a similar group connected either delta-delta or star-star as the terminal voltages would be different. Two transformers connected in open delta or in "V" may be operated in parallel with three transformers connected star-star or delta-delta. E. G. R.

39—Carrying Capacity of Conductors. What is the maximum amount of current that may be carried by rubber covered cables when used as leads, with testing instruments; also magnet wires, in the interior of lamps, instruments, etc.? I do not mean the maximum safe carrying-capacity as given by the Underwriters, but to avoid using clumsy cables, when testing and the like. I want to know the smallest size possible with a given current and not have the insulation endangered by the heat of the wire. E. R. R.

Use double the values given by the Underwriters' Rules. Deterioration takes place in rubber insulation even if the conductor be carrying only ordinary currents. It will probably be found that for testing purposes, the cables will stand the currents that would be obtained by the above rule as long as they will the wear and tear of handling in testing work. Asbestos-covered or enamel-covered wire is more serviceable than rubber-covered in arc-lamps, etc., where it is desired to employ a higher current density.

40—Three-Wire Generator. In converting a direct-current machine to a three-wire generator what is the process of locating the right bars to be tapped for collector ring leads? L. W.

The alternating-current connections for a direct-current generator are the same as for a two-phase rotary converter, the connections being made ninety electrical degrees apart. In the multiple wound machines, the

armature winding between similar poles is divided into four equal parts and the connections are made at these points. In a two circuit winding, the entire armature is divided into four parts and the connections are made so that one-quarter of the total armature turns are between each connection. W. A. D.

41—THE SHORT-CIRCUIT CURRENT OF AN ALTERNATOR remains almost constant from normal speed to nearly zero speed. What is the explanation of this? H. M. M.

The frequency is, of course, proportional to the speed. The self-induction of the armature decreases as the frequency decreases, but at a greater rate, so that, although the voltage decreases in proportion to the decrease in speed, the decrease in self-induction is such as to maintain the short-circuit current nearly constant. F. D. N.

42—Are there any recent rules of the National Board of Fire Underwriters applying to large power houses? It seems that the regulations embodied in the regular National Electrical Code do not apply to this class of buildings. B. M. K.

We know of no rules being formulated or of any meeting for such purpose on the subject of large power houses. C. M. G.

43—WATTMETER ON LOW VOLTAGE. Will a 500-volt, 50-ampere direct-current integrating wattmeter register correctly if used on a 250-volt circuit, and if so, please explain the theory by which this can be proven. Is a direct-current integrating wattmeter independent of voltage, provided, of course, the rated voltage of the meter is not exceeded? J. E. F.

Any direct-current meter will register correctly within three to four percent on one-half its normal voltage. The meter will usually register slightly more than the correct energy. The theory for this action is that the torque of a direct-current meter or motor is proportional to the product of the magnetic fields produced by the armature and magnets. In a direct-current meter, the speed is so low and field so weak that there is no appreciable counter-e.m.f. As the armature is the shunt element in this type of meter its current is proportional to the potential of the circuit on which the meter is operating. W. B.

44—COST OF RAILWAY CONSTRUCTION. In the article on "Railway Location and Construction" in the February issue, page 110, second paragraph, is the following sentence: "The cost of construction increases with the decrease of grades and curvature." Is this sentence correct? In other words, does the cost of construction increase with decrease of grades and curvature? G. A. H.

The cost of construction in a given country increases with the decrease of the rate of grade because the use of easier grades necessitates more expensive grading work. Likewise the cost of construction increases with a decrease in degree of curves, because flat curves always mean a more direct route, and consequently there is less opportunity to avoid heavy grading work than there is with shorter and sharper curves. Thus a steam railroad, with easy grades and curves of large radius, is more expensive than a street railway with heavy grades and sharp curves, although the street railway is much longer. H. E. W.

45—GROUND DETECTOR. What is the best ground detector apparatus for a central station of about 3 300 kw.? The generators are 440 volt, 25-cycle machines entirely for power service. There are six motor circuits each of 500 M. cir. mils, two circuits of 600 M. cir. mils and two of 700 M. cir. mils. E. J. S.

Owing to the low voltage the usual static ground detectors cannot be used. A voltmeter, with plugs arranged to connect the voltmeter from the various lines to ground, is the usual practice in such cases. P. M.

THE

ELECTRIC JOURNAL

VOL. V. APRIL, 1908 NO. 4

Meter Testing Departments

The article on the "Meter Testing Department of the Hartford Electric Light Company" by Mr. F. W. Prince in this issue of the JOURNAL should be of especial interest to central station meter superintendents in that it clearly outlines what should be a basic principle in every central station, namely, that a systematic method of handling the meter department is essential. That so successful a company as that which Mr. Prince represents has deemed it wise to equip and maintain such an extensive meter department as indicated by the description, should convince other central station managers who have been neglectful of this department that it is good sound business judgment to emulate the Hartford example.

Too many central station managers regard the meter department as one of minor importance, with the result that but indifferent if any attention is paid to the equipment for testing and maintaining the service meters. To those familiar with the metering problem it seems strange that so many managers will spend large amounts of money, thought and time in planning improvements in the generating apparatus or distribution systems in order to effect a comparatively small saving and then permit many times this possible saving to "leak out" through neglect to keep the integrating meters in proper condition.

To the smaller central stations the purchasing of a reliable and efficient testing equipment has been a more or less serious problem, as the amount of money involved in the purchase of a complete set of standards would be a comparatively large percentage of the total amount of money invested in the service meters. With the recent development, however, of the so-called "rotating" standard wattmeter having several ampere and voltage capacities the question of expense is no longer serious as the meters are reasonable in price and one standard will cover a large range of service meter capacities. Again, the use of rotating standards materially reduces the expense of testing, as one man can now test approximately ten meters per day, whereas, with the older method, involving the use of indi-

cating wattmeters, stop watches and slide rules, it usually required two men whose testing record would seldom average more than seven or eight meters per day. A further advantage in the use of the rotating standards for testing service meters is that the load need not be kept constant and any desirable load such as a lamp bank or house load can be used.

In conclusion it may be said that in view of the comparatively low priced commercial standards now offered but little excuse exists for a central station meter department being improperly equipped or permitting service meters to become so inaccurate as to cause serious loss in revenue.

H. W. YOUNG

Scientific Aids in Industrial Work

The JOURNAL has opportunity from time to time to present articles which differ from the ordinary. Most of its reading matter relates to specific things, to engineering principles or construction or operation. Now and then an article takes a broader point of view, it deals with general purposes and methods, it treats not merely of the work of some specific department, but it shows how many lines are inter-related, and from an elevated position the writer views an extended field of action and makes clear conditions and relations which may not have been recognized or clearly perceived. Such an article is the one by Mr. Skinner in this issue of the JOURNAL.

The title, "Commercial Research," may make different and possibly indefinite impressions on different minds. Few, however, will not have an enlarged view of the subject as they read the article. First of all, the words "Commercial" and "Research" do not ordinarily go together. To many minds the term "Research" suggests the laboratory where a learned professor or a theoretical student is trying to analyze or measure or find out something which is unknown and is usually impractical. It may amount to something sometime, just as Faraday's researches have quite a useful effect upon the electric development of to-day. On the other hand, the term "Commercial" suggests the doing of something which has money and profit connected with it. It is the old problem of the Theoretical vs. the Practical. Probably the solution lies somewhere between the two extremes and contains more of the other side than either advocate at first imagines.

A large measure of the application of scientific principles and methods to practical needs and progress lies in the field which Mr. Skinner terms "Commercial Research." The field and the method are presented in a way which will be enlightening to nearly all who have to do with electrical apparatus and manufacturing operations. Those who furnish materials to a manufacturing company and those who use its product, the shop foreman and the purchasing agent and the general manager, as well as the engineer and designer, have an interest directly and indirectly in this paper, and the student who wonders how he will make future use of his technical knowledge will also find much to consider.

How to bring scientific knowledge to bear effectively upon commercial progress is a vital question. It is the problem of the manufacturing company, it is the problem of the technical school and it is a problem for the individual engineer. This is, broadly speaking, the problem which Mr. Skinner considers.

The reader will note how much scientific methods (as distinguished from scientific knowledge) are emphasized. The admirable dissertation upon "Methods of Work" and the analysis of different methods of procedure when a question is to be investigated will appeal to many who have nothing to do with commercial research.

The real value of the article is that it does not present a scheme synthetically constructed upon abstract principles, but is a working code deduced from experience. The receipts for locating trouble are the result of personal experience and observation by a man who assimilates experience and who merely preaches what he has already practiced.

The concluding paragraph is worthy of larger emphasis. After all is said about the field and importance of scientific aids in industrial work and the methods of securing reasonable and efficient results, the final element is the human element. The same balance between the theoretical and the practical, the same accuracy and analytical common sense which are essential in the methods of work are likewise essential in the man. He is not likely to succeed if he lacks attention to detail, or is unable to see anything but detail; or if he lacks initiative and resourcefulness; or if he is unable to distinguish cause from effect, or lacks concentration or is unable to adopt himself to surroundings and co-workers.

CHAS. F. SCOTT

Natural Resources and Engineering Societies

The President of the United States has invited the the presidents of four National Engineering Societies to take part in the conference, to be held in a few months, on the preservation of our national resources to which he has called the governors of the states. The invitation to the Engineering Society Presidents is significant. It recognizes the scientific and engineering basis which should underlie legal enactment. It recognizes the heads of the national societies as the source from which engineering counsel may be forthcoming.

This affords an opportunity to the engineering profession to take an active part in what may become an undertaking of far-reaching importance. It affords an opportunity for joint action by the four presidents which will put the engineering profession, as represented by the four societies, in a position to aid and support the plans and recommendations which from the engineering standpoint may be found wise and expedient. It affords an opportunity for the engineering societies to take interest in matters outside of the domain of the usual professional work and promote measures which involve engineering, economic and legal questions and which are of vital consequence to our future prosperity and progress.

CHAS. F. SCOTT

COMMERCIAL RESEARCH*

C. E. SKINNER

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RESEARCH may be defined as diligent and protracted investigation, especially for the purpose of adding to human knowledge. Commercial research is naturally, therefore, investigation undertaken for the purpose of adding to human knowledge with the direct view of securing commercial returns in a reasonable time. The true scientific investigator rarely thinks of commercial results, but is completely absorbed in gaining new knowledge on the subject in hand. The astronomer does not study the question of life on the planet Mars with a view of producing commercial results, and it is probable that no eclipse expedition has ever shown financial returns sufficient to warrant the expenditure of the time and money necessary to carry on the expedition. The highest order of research is that in which the investigator labors to add new knowledge to that already gained and to widen the horizon in whatever field he may be engaged. The addition of new knowledge on any subject is of both permanent and economic value, although the results of such additions may not be apparent until decades after the knowledge has been gained. Motley has said in his "History of the United Netherlands," that no generation lives long enough to reap all the results of its deeds—either good or evil; and this is just as true in regard to contributions to our knowledge of the laws of nature. Witness the work of Galileo, of Franklin, of Faraday, of Kelvin, and of a host of others. Years ago Hertz demonstrated that electric waves could be transmitted several feet without the use of wires. To-day, by the same means, we are in communication with the continent of Europe, and yet he would have been a bold prophet who would have declared from the consideration of the work of Hertz that such a result would ever be accomplished. Who can say what results for good may accrue to future generations from our present-day study of radiant energy or the ultimate composition of matter?

But many of us may not be privileged to study science for the pure love of science, but must become a part of the great industrial machine which takes scientific facts and phenomena and weaves

*An address delivered before the Engineering Assembly of Purdue University, January 20, 1908, and The Electric Club, January 27, 1908.

them into a fabric of machines and devices which have to do directly with the commercial advance of our own times. This paper will, therefore, be confined to commercial research, and an endeavor will be made to point out some of the conditions which surround those carrying on this class of work for a large corporation, where commercial results must be kept in view no matter how absorbing the work may be from the purely scientific standpoint. It should be unnecessary to emphasize the commercial element in connection with research work, as profitable results from labor performed are a condition of existence to far the greater part of the human race. It may not be possible to draw a sharp line between the commercial and the non-commercial, as the most promising fields for commercial investigation sometimes turn out to be entirely barren of commercial results, while work undertaken with no commercial end in view may yield the most surprising returns from results which are totally unexpected. Or, again, research undertaken with one object in view may result in the development of a totally different product. A splendid lubricant is the result of an attempt to manufacture artificial diamonds; a printer's ink is the result of an attempt to make quartz tubes in the electrical furnace.

The problem of commercial research will be dealt with as seen from the writer's viewpoint, and it will therefore be in a measure the reflection of the work in which he is engaged. It may seem that some of the points made are entirely foreign to research work, but these are included as they happen to come within the writer's experience, and they may have more bearing on the subject than is at first apparent.

The research work of a large corporation may be divided into the following classes:

1—Investigation of the properties of materials.
2—Development and investigation of processes.
3—Investigation of phenomena affecting design.
4—Determination of results of design.
5—Development of new classes of apparatus.
6—Critical study of existing designs.
7—Investigation of the causes of failures.
8—Investigation of crank schemes, scientific fakes, etc.

INVESTIGATION OF THE PROPERTIES OF MATERIALS

The basis of all manufacturing is the conversion of raw ma-

terials into finished products, the finished product of one manufacturer often being the raw material of another. The variety of materials used in a large manufacturing corporation is very great, a rough estimate showing that more than five hundred classes of so-called raw materials are involved in the product of the company with which the writer is most familiar. The determination of the properties of such a large variety of materials covers the whole scale of chemical, physical and electrical tests and measurements as made both in the laboratory and under service conditions. The necessity for a more intimate knowledge of the properties of all the materials entering into a product is becoming more and more evident, and it is becoming more customary to express this knowledge in the form of specifications giving the characteristics of the material required. It is rare that a satisfactory specification can be written without considerable previous investigation into the properties, tests, method of production and other features of the material in question, even though it be of a well known grade on the market. Such specifications, to be of use, must be so written that material purchased and tested under the specification will be a satisfactory product to the manufacturer and to the purchaser of the material.

In some cases investigations follow well established lines of chemical, physical and electrical tests; in other cases new tests must be devised in order to demonstrate whether or not the material in question is suited for the particular use to be made of it. Thus, steel for high-speed turbo-generator fields must be tested with respect to its physical properties, its magnetic characteristics and its machining qualities, and the design of such fields must of necessity depend on the commercial grades of steel which can be found which are most suitable for the particular purpose in view.

There is a continual demand for new materials and new combinations of materials to meet new and special conditions, and this opens a very wide and fertile field for the investigator. Some of the remarkable advances which have been made in industrial lines in recent years have resulted from such new applications, as, for example, the increase in the efficiency of electric lighting devices of various kinds by the use of hitherto untried materials for this purpose. The requirements for steel of very high tensile strength in automobile and other work has led to the exploitation of the alloy steels and the placing on the market of steels with properties of tensile strength and ability to resist shock that were totally unknown a very few years ago. The work done so far in this particular line

has been so advantageous to manufacturers that the whole field of alloy steels will no doubt be investigated in the near future, with the result that designs both mechanical and electrical may undergo a complete change in a comparatively short time, just as the evolution of high-speed tool steel has required a revolution in the design of machine tools.

In the use of new materials and new applications of old materials results are frequently encountered in practice which were totally unexpected, and, where trouble results from the emphasizing of any particular property, an elaborate and costly set of experiments may be absolutely necessary to overcome the trouble. In the development of high-tension transformers for long-distance transmission work, mineral oil was found to be a satisfactory and cheap insulating and cooling medium. When transformer units of larger size were needed, cooling by radiation from the case became impractical, and water-cooling coils were introduced into the case. Trouble resulted, due to deposits from the oil settling on the cooling tubes, and, as these deposits were heat insulators, the efficiency of the cooling system became impaired. An investigation was required to determine the cause and prevention of these deposits. On account of the very complicated chemical structure of mineral oil, the investigation proved to be very difficult both as to determining the cause and finding a cure for the trouble. After making hundreds of tests on many kinds of oil, it was possible to eliminate the effect of the electro-static field, the effect of the combination of the oil with other insulating materials and metals used, and many other features which it was thought might be responsible, and to resolve the problem into one of the simple effect of temperature. Oil chemists and others consulted did not think it possible that deposits of this class in sufficient quantity to cause difficulty, could result at a temperature not exceeding 80 degrees C., but such was proven to be a fact. When this was proven, it became necessary to make further investigation to determine what oils, if any, would be free from this effect, and, after another series of tests, a material was found which met all practical conditions. When such a problem as the above is presented, where the material under investigation is itself a complicated one and there are a large number of conditions which might cause the trouble, the solution almost invariably requires some time. Fortunately for the commercial side of the question, many of the problems presented are more easily solved than the one mentioned.

It may be that some property of a material is of no particular importance in ordinary work but becomes of prime importance in some particular design. In such cases it is usually necessary to study this particular property with respect to the design in hand. In making physical tests of certain bronzes, for example, the elastic limit or yield point as taken in the ordinary way would be given as a certain definite figure. When this bronze is applied to the mechanical parts of high-speed machinery where the stresses are great, failure may result from the fact that the so-called yield point is not a point at all but a curve, a slight amount of yield taking place at stresses far below that ordinarily given. Lack of knowledge of this fact and of the amount of yield for different stresses may cause failure in important work.

Many properties of materials which are well known are yet without really satisfactory methods of measurement, as, for instance, the hardness or softness of copper used in electrical work, hard copper being required for commutator work and soft copper for coil winding. It is not difficult to say that the material is hard or soft; it is nearly impossible to say how hard or how soft. Also it is extremely desirable to know the relative heat conducting properties of insulating materials and the relation of these to dielectric strength, but these determinations are exceedingly difficult to make with any degree of satisfaction. While apparatus is available for the determination of dielectric strength of insulating materials, exact determinations are difficult on account of inevitable variations in the materials themselves. Innumerable examples of this kind could be given, but those mentioned will serve to illustrate the point.

DEVELOPMENT AND INVESTIGATION OF PROCESSES

The word "process" will be used here to distinguish the treatment and application of materials to meet the conditions of manufacture from the usual mechanical operation such as machining, assembling, etc. Every manufacturing company has its special application of materials, and in very many instances combinations must be made or treatments given to fit commercial materials to these special applications, these treatments usually being to change or to better their quality. Also, methods of manufacturing or of making combinations must be devised to fit the particular work in hand. Press paper, or fullerboard as it is sometimes called, is used in many kinds of work besides electrical, and each class probably

requires its special treatment. In electrical work it is used largely for insulating purposes and is usually treated with varnish or oil to increase its insulation strength. Sheet steel, as used for transformers and machines, is usually annealed to lower its losses. The metals, such as copper, tin, aluminum, zinc, lead, etc., are combined in various proportions to form alloys for mechanical and electrical purposes. Special cements, varnishes and paints may be made from the raw materials or by combining standard market grades. Mica is bought in bulk and converted into many forms of insulating material by splitting, pasting and baking. All machinery is finished by the application of some material to serve as a protection and to enhance its appearance. The application of such finishes or the development of new finishes comes within our definition of the term "process."

Process work is very closely interlinked with the investigation of the properties of materials, the investigation of phenomena affecting design, and the determination of the results of design, so closely indeed that it may be hard to distinguish in a given case whether an effect may be due to the properties of the materials or to the process which has been followed in the preparation or changing of the characteristics of the materials. The development and investigation of processes form no small part of commercial research. In the development of processes the investigator very frequently must familiarize himself very intimately with the properties of all the materials involved, with the various methods which may be followed in handling these materials, and with the results which must be obtained in the finished product. The process of treating coils to secure the best possible insulation, the best possible dissipation of heat and the best possible mechanical results may call forth the investigator's highest endeavor in the study of the materials involved, the methods of procedure to be followed and the application of the results when obtained. Processes well worked out and carefully recorded will form the basis of further development when this becomes necessary.

INVESTIGATION OF PHENOMENA AFFECTING DESIGN

All rational design is based upon the disposition of materials in such a manner as to take advantage of phenomena, usually related to the law of the conservation of energy. For example, a steam engine is a combination of materials so disposed as to be capable of

transforming heat energy into kinetic energy; a dynamo is a combination of materials so disposed as to be capable of transforming kinetic energy into electric energy; an incandescent lamp is a combination of materials so disposed as to be capable of transforming electric energy into light. In speaking of phenomena affecting design, it is intended to distinguish such phenomena as static discharge, magnetic flux, flow of current, dissipation of heat, etc., from the properties of materials which have been previously discussed. The designer needs to know the physical laws (that is the relations) and the constants (that is the absolute values) of these phenomena. Innumerable phenomena such as magnetic flux, potential gradient, magnetic pull, heat dissipation, etc., enter into conditions which must be taken into account in design work; and the more intimate knowledge a designer has of the phenomena affecting his designs, the better designs he is able to make. As in the case of properties of materials, our knowledge of phenomena of the class under consideration is relatively imperfect, and, no doubt, perfect knowledge of all phenomena will never be reached; consequently, we can use our utmost diligence without fear of exhausting the subject.

New phenomena affecting design and new phases of well known phenomena are continually arising in all progressive work, and such phenomena require investigation. A change in the form of a magnetic circuit will change the flux distribution and possibly seriously influence the final result. Varying the proportions of a magnetic circuit, for example, may vary the total losses in different parts and the relations of these losses to each other in such a way as to completely offset figured gains, when the knowledge of such phenomena is not perfect. In such cases a very thorough and exact analysis is often required to determine where the trouble lies. A well known electrical meter which had been on the market for a number of years and giving entire satisfaction was slightly changed in construction in order to cheapen the product, the change consisting in substituting a thin iron casting for a thin brass casting in the meter case. The accuracy was seriously impaired and investigation proved the trouble to be a case of deranged flux distribution.

The heat dissipating power of field coils is very greatly changed by change in the method of insulating, and the difference in the heat dissipating power of different designs is sufficient to make many dollars difference in the cost of even small size generators

having identical performance. The potential gradient through insulating materials as applied to cables, transformers, and high voltage apparatus in general, requires very careful study in order to make the most efficient use of the insulating materials which enter into their construction. One design with a large amount of material may fail where another design with a much smaller amount of material succeeds, due to the concentration of potential in the first design on certain small portions of the insulating material, causing breakdowns. This particular phenomenon has been but little understood and much less provided for until within a very recent period. Theoretically, an insulated cable should have a material of very high specific inductive capacity next the core, with an almost imperceptible shading from the core to the outside of the insulation, the rate of shading depending on the size of the conductor and the voltage to be used. It is obvious that such an insulation is commercially impossible; consequently, the best compromise which can be made commercially by successive layers of uniform quality will yield the best practical result.

It will be seen from the above that the various phenomena which have been distinguished from the properties of materials are so interlinked with these properties that the two must be studied in conjunction with each other. Again, the closer and more exacting the design becomes in the attempt to secure better performance or cheaper apparatus, the more accurate must be our knowledge of materials and phenomena. As the design becomes more nearly perfect, further gains are harder and harder to make. It is not at all difficult to design a transformer so as to get on efficiency of 97.5 percent; 98 percent is attainable on large sizes, and 98.5 percent with very special care and proper proportioning of materials. An efficiency of 99.5 percent is commercially impossible with the materials and the knowledge of phenomena now at our command. It is not particularly difficult to get an integrating meter for commercial service accurate to within one percent; an average accuracy of one-tenth of one percent is not only exceedingly difficult of attainment, but usually unnecessary as well. The design of a magnetic field so as to result in a comparatively small percentage of magnetic leakage is entirely feasible, while, with commercial apparatus, a design with no leakage at all is simply unattainable.

DETERMINATION OF RESULTS OF DESIGN

As already pointed out, our knowledge of the properties of ma-

terials and our knowledge of phenomena which are to be taken advantage of or avoided in design work, are in both cases far from perfect; and, furthermore, the different phenomena to be taken account of may be directly opposed to each other, so that, even with a perfect knowledge of properties and phenomena, the design would at best be a compromise. In fact, all design is a compromise, the best designs being those containing the most that is satisfactory and excluding the most that is unsatisfactory. In order to take the best advantage of the expansion of steam in a steam turbine, a very high speed is necessary. This high speed has the advantage of reducing the amount of material required in both engine and generator; it has the disadvantage that the centrifugal forces in the revolving parts become so great that materials must be very carefully chosen and very carefully used, in order to make the design strong enough to withstand these centrifugal forces. All electric circuits must be insulated with some material which will confine the flow of current to its intended path. All conductors oppose resistance to the flow of current; consequently heat is developed. All insulating materials are non-conductors of heat in a greater or less degree; consequently in the design of the winding of an electric generator there are requirements which are diametrically opposed to each other. The result is therefore a compromise between these two requirements, and the best design is that which gives the required insulation with a maximum of cooling. Again, in an incandescent lamp, the best light efficiency is obtained at very high temperatures, but the materials ordinarily available for incandescent filaments reach their limit of life very quickly if certain temperatures are exceeded, these temperatures being below the efficient point for the production of light. Another compromise is necessary. An examination of the results of a design will consist, therefore, of making tests on the various features involved and determining whether or not the best compromise has been effected between the conflicting elements which enter into the particular design.

Frequently new features arise which were totally unforeseen and which require careful and elaborate investigation. A machine which meets the designer's expectations in every feature included in the specification may develop a noise from the flow of air or from vibration in the laminations, which totally unfits it for the service intended. As a matter of fact, the testing of a machine or meter to determine whether or not it meets the customer's or the designer's specifications is not considered research work. The research

engineer is called in only when the causes of failure are to be investigated or the study of new phenomena developed is required.

DEVELOPMENT OF NEW CLASSES OF APPARATUS

New apparatus and new machinery are continually being demanded to meet the new conditions which arise, and probably no decade in the world's history has seen such strides in this direction as the present. New appliances are developed, which in themselves create an apparent need for further developments. It is sometimes comparatively easy to create a market for a clever or taking design where no such need was really felt at all until the public's attention was called to it. Single inventions and discoveries have opened up totally new fields of investigation and have required research work of the highest order extending over long periods to again equalize the field and produce all the apparatus necessary to take care of the demands created by such inventions and discoveries.

Every device must be thoroughly tried and should be looked at from every point of view before it is sent out to take its place among the innumerable devices now available to add to our comfort and convenience, and the engineer who can make his tests and his examinations with the largest vision is the one who will have his devices remain longest on the market. Every characteristic of the device in question should be investigated. Every feature which tends to success should be carefully conserved; every feature which tends to failure should, in the greatest measure possible, be eliminated. Instructions to follow out these simple statements may mean investigation on a single device extending over a period of months. Take, for example, the wonderful activity which is going on at present in the development of new devices for incandescent electric lighting. Before the tungsten lamp can be put on the market as an assured commercial product, its many characteristics, which are so radically different from those which we have been accustomed to consider as a feature of incandescent lamps, must be studied to the extent necessary to insure that these characteristics will prove satisfactory in operation; and, again, the commercial side of the question must be considered and the cheapest form which will give satisfaction must be developed. In this particular case the brittleness of tungsten is a great handicap to the use of an otherwise eminently fitting material.

No design for any apparatus can be considered perfect, and in

commercial work it is usually necessary for engineers to recognize that, while they can always see features in a design which can be improved, other and more potent reasons may exist which make it impossible for them to take advantage of the changes which they might possibly make and which would better the particular design. This is especially true in the business of a very large corporation where manufacturing must be done on a large scale and where a slight change in one piece of apparatus which forms part of the manufacturing plan, will very seriously derange that plan and cause a loss which will be greater than any possible gain which might be made by the change on that particular apparatus. The lesson is obvious. All the phenomena and conditions which surround these changes which will better the particular design should be carefully studied in the existing designs and the results stored away for future use, and, when new designs of the same general class are to be put out, advantage may then be taken of all this accumulated experience.

CRITICAL STUDY OF EXISTING DESIGNS

In order to get the necessary breadth of vision to insure success it is absolutely necessary that the engineer or designer be familiar with the apparatus of the class with which he has to do, not only of his own design, but of whatever designs may be on the market. It is very noticeable that the designers who are the most successful are those who are continually making a critical study, not only of their own, but of other designs of the same general class which come within their observation. In such study the same method of examination and test as applied to his own designs, should be followed out, and the designer should have sufficient breadth of mind to fully appreciate the good points as well as the bad points of the designs of others. Every one should train himself to criticise constructively as well as destructively. While it very frequently happens that it is even more important to know what not to do than to know what to do, still if one does not know what to include, he must learn by tests, measurements, etc., or his designs must fail. If a designer does not study existing designs on the market and develops along his own lines without interference, it is almost inevitable that faults will creep in which in the end will lead him far astray from the best that could be accomplished.

INVESTIGATION OF THE CAUSES OF FAILURES

Those connected with the research work of a large manufacturing corporation soon find that the investigation of the causes of failures and the devising of means of preventing a repetition of such failures is no small part of their work. Indeed, some of the most difficult and exacting work to be done is of this class. Not the least part of the difficulty lies in the fact that results are often demanded even before the investigation has begun. In many cases also the failure destroys all evidence of the cause, or the incidental results of the failure are so great as to completely distract attention from the real cause.

The most frequent general causes for the failure of any product are: 1—Faulty material; 2—Faulty workmanship; 3—Errors in design; 4—Immature state of development of the art; 5—Improper application; 6—Lack of care by operatives, and 7—Development of new and hitherto unknown phenomena.

While our knowledge of the properties of materials is far from complete, it can also be said with equal emphasis that our knowledge as to the cause of faults in materials and methods of preventing them is equally incomplete. The physical properties of a given grade of steel may be well known and yet have failures of the most mysterious kind. Copper wire sometimes has the necessary conductivity and yet develops brittleness to such an extent that it is totally unfit for armature work, and yet a physical test of the wire one inch from the break may give no index as to the cause. An insulating varnish may fail and a long investigation be necessary to prove that the whole trouble was due to a little water in that particular lot of varnish. These are all examples from experience and it would be very easy to fill many pages with the recitation of similar examples. Some one has said that this class of faults is due to the innate depravity of inanimate things. If there is depravity in materials, how much more exasperating it is to conduct an investigation of a "trouble job" only to find that design, materials, and all conditions were satisfactory and that the trouble was due to the absolute carelessness or ignorance of some workman.

An engineer naturally does not like to admit that there may be an error in his design, yet college educated men are not entirely free from faults of carelessness and even ignorance. The addition "$4+6=9$" may make the coil throw of an armature one slot short, and the time of half-a-dozen high salaried men be required

for half a day to determine why the machine does not operate properly. More excusable is the engineer if he is working in a relatively new field and his design embodies principles which have never been proven erroneous, but nevertheless an investigation into the cause of the trouble is no less necessary and troublesome. Several fires occurred in some large air-blast transformers, a large number of which were installed for one operating company. In each case the damage was such as to warrant almost any assumption, such as defective insulation, careless work, insufficient spacing of terminals, careless handling, static disturbances, surges on switching, etc. The first transformer dismantled was burned almost beyond recognition, but as it was taken apart the coroner noticed at one point near the top of the laminated iron, two sheets in the opposite limbs of the transformer, each having a burned spot perhaps one-eighth by one-quarter of an inch. Closer examination showed that an arc had been formed between these two sheets. A study of the design showed that the two limbs of iron were resting on a common base and were held in position by wooden blocks at the top. The cause of the fire was at once evident. The base and laminations which were not perfectly insulated from each other formed a U-shaped conductor and two sheets touching closed the circuit and started an arc, which, being in contact with the wood, soon set it on fire, and the air blast and resulting short-circuit did the rest. The remedy was also easy to apply. Either perfect insulation of the two parts or short-circuiting them by a neutral plate was satisfactory. With that experience in mind, it would be inadmissable for the same engineers to have a recurrence of the trouble. All such faults as these may be very easy to remedy, when you know the cause, but you must first find the cause.

INVESTIGATION OF CRANK SCHEMES, SCIENTIFIC FAKES, ETC.

In this day and age when nothing seems to be impossible, it is necessary for every enterprising corporation to make sure that some hitherto unknown material or process or phenomenon has not made possible the extravagant claims that are continually brought to its attention. Sometimes these claims are made in good faith (often the inventor in his enthusiasm is led to believe that an invention of some merit but of very minor importance, will revolutionize the world of science) ; and sometimes they are pure fakes and are only intended to be a means of filching money from the credulous. A

good grounding in the fundamental physical laws with a dash of plain, ordinary horse-sense instilled into every would-be inventor would go far to reduce the number of investigations necessary for the first two classes. Nothing short of a diploma from a state penitentiary will stop the exploitation of such schemes as that of a motor which gets colder as its load is increased, a chemical which will turn brass into gold or a furnace which gives out more heat units than are put into it. By far the greater share of investigations of the classes referred to are for people who have some education, but not enough to familiarize them with all the necessary facts. A man devises a new kind of insulating material and thinks it should revolutionize the whole electrical business. A workman, knowing that mica was used in commutators, spent years trying to melt and cast mica in the desired form. He died, leaving his secret to his son. The son, sick and in want, offered to sell the precious secret for the paltry sum of ten thousand dollars. A railway journey of a thousand miles and a test conducted behind barred doors with the utmost secrecy and dramatic flourishes showed that; while he had succeeded in melting mica, the product was worthless. Schemes for tempering copper are so numerous that a stereotyped reply has been prepared to send to the inventors. These and many more schemes require attention, and, in making reports, one must sometimes harden his heart to the pathos and tragedy of years of hardship and toil spent in the pursuit of a will o' the wisp. The scientific fakir rarely troubles the scientifically conducted corporation, but preys on the dear public, and it is only occasionally that some one asks to have an investigation made to complete his education on fakes. A company was being exploited to manufacture a perfect insulator for lines of force. After considerable trouble a demonstration was secured. A permanent magnet used would attract iron. With the insulator interposed between the magnet and the iron, no attraction resulted. The "insulator" proved to be a piece of galvanized iron.

METHODS OF WORK

Quite a good deal has been said about the problems to be solved. How shall we set about the solution? How shall tests be made? How elaborate shall the experiments be? What accuracy will be required? These and many other questions must be answered before the work is well begun.

In general, each investigation, whether simple or elaborate, should begin where a previous one left off and all the knowledge of the subject that can be gleaned from any source should be taken into consideration. It should not be necessary to determine the temperature co-efficient of copper, for example, when a set of experiments involve the measurement of temperature rise by the resistance method. Much depends on whether the work to be undertaken is to give additional information on a subject already fairly well known, or whether it is to be in a new and unexplored field. The equipment and precautions to determine the dielectric strength of a given insulating material will be much less elaborate than the equipment and precautions required to study the laws of potential gradient in the different insulating materials as applied to transformer insulation. The elaborateness and cost of an experiment should be governed by the necessity of the case and the probable value of the results. It may be desirable or even positively necessary to develop an insulating cement, but such development would not warrant the investigation of the whole field of materials and methods which might produce such a cement. If there was any chance that an alloy of copper and aluminum would have twice the conductivity of copper, no expense would be too great to reduce the possibility to commercial practice. Extreme accuracy may be required in one case while time is positively wasted in another in trying to get an accuracy closer than ± ten percent. It is not that extreme accuracy is objectionable in any set of measurements, but sometimes it is either impossible or unnecessary. Sufficient accuracy for the purpose should be obtained; greater accuracy should be dispensed with if it costs too much time and money.

Some classes of research may be such as to be productive of very positive and definite results from a few comparatively simple experiments, while in other classes hundreds or thousands of tests must be made before any satisfactory conclusions can be drawn. The action of a core plate varnish and the design of machinery for applying it may be successfully determined from tests on a few pounds of sheets, while the application of the process may extend to thousands of tons. Positive assurance that a certain grade of mica is entirely suitable for commutator strip insulation can be given only after hundreds of tests have been made in actual practice after it has passed the best laboratory tests available.

It should be apparent therefore that no general rule can be laid down for the conduct of commercial research work. Each problem

must receive specific attention, and the necessary results must be arrived at with the least possible delay and expense. Some general observations as to methods of attack may, however, be of value. General methods of procedure may be classed as follows: 1—Cut and try method; 2—Step by step method; 3—Try everything method; 4—Elimination method; 5—Checking theory method, and 6—Combinations of any two or more of the above.

The cut and try method may be likened to the locating of a fault in a cable or an armature winding by cutting in halves and determining in which half the fault lies. Then, dividing this half, again locating the faulty part, and so on until the faulty section or coil is found.

The step by step method is very similar to the cut and try method, but in this method each step is based on more definite conclusions drawn from the previous steps. This is the most efficient method to be followed in exploring an unknown field, especially if theory is not sufficiently developed to give material aid. Indeed, it is the only method that can be commercially followed in the development of large machinery or costly processes. The development of the single-phase motor for railway service is the result of many steps and, while theory has aided in each step, many steps have been taken since the first commutating single-phase motor was built. The development of large turbo-generators must of necessity be accomplished by this method. The step by step method will usually be found to be the best for any development, even though it may take longer than others, but rare judgment will indeed be used if a step backward is not taken at times by the most experienced investigator. We may compare this method to the plotting of a curve as the various points are determined, while the "try everything" method which follows may be compared to filling in each square of the cross section sheet and then assigning values to each in an endeavor to get the trend of the curves. True, many of the values will be zero and require no consideration. The experimentor may have the satisfaction of feeling that he has covered the entire field, but it is seldom that there is any warrant for following this method. Probably no more exhaustive and satisfactory experimental work was ever done by this method than that by Thomas A. Edison in his development of the incandescent lamp. For nearly twenty years it was thought impossible to improve upon his work except by adding a little improvement of material here or a nicety of method there. Within a year or two, however, a whole new field

has opened up by the use of metalized and metal filaments, so that the carbon filament of Edison will probably soon be a thing of the past for many classes of work.

The eliminating method should probably have been given first place, as it should always be used with each of the foregoing, and its application will usually reduce the time and expense involved in any investigation. In this method every material or every process that gives any promise whatever is tabulated, together with its properties or its characteristics as far as known, particularly those that affect the problem in hand. The theoretical requirements of the result are then set down and every material or process having a single characteristic that would unfit it for the result desired, is rejected. The doubtful characteristics of the remaining materials or processes are next tested and a further rejection made. By following the above plan, a problem that at first assumes gigantic proportions may soon be reduced to relatively simple proportions. A flexible insulating varnish for a specific purpose was desired. Twenty or thirty varnish gums are on the market. By following the elimination method it was necessary to experiment with but two or three. It was definitely determined that the others were not suitable by a consideration of their known characteristics.

Perhaps the highest order of commercial research is that which has for its object the proving of theory, and the experimenter best grounded in theory will require the fewest tests to arrive at his conclusions. Perhaps the best example of this class is the development of the Pupin coils for the artificial loading of telephone cables. Here, experiment was based on purely theoretical considerations and the economic and financial returns were very great.

APPLICATIONS OF RESULTS

It is rare that one man combines the power of brilliant investigation with the power of making commercial application of his results. Some of the most useful inventions and discoveries have left the hands of the inventors in a state utterly unfit for the market. In the large corporation research work must be done, results must be reached and applications must be made of them if that corporation is to keep in the lead. In no business is this so true as in electrical manufacture. The application of results must, therefore, be kept in mind, be they positive or negative. On account of the division of labor in any large corporation, it may not be necessary

for the individual who directs the investigations to apply the results, but he must at least know that they will have some application. The fundamentals of the process of electric welding may be developed by one experimenter. Others may design the machinery and perfect the process. One man may develop a process for producing enameled wire; a dozen others may make use of it in their designs. Other things being equal, the experimenter who has the most intimate knowledge of the products of his company will be the most likely to produce results from his investigations which can be applied to useful purposes. A process for the ozonization of drinking water may be of no value if it is not the intention to include apparatus for carrying out the process in the company's product. Without developing this phase of the subject farther, enough has probably been said to show that research is not commercial unless the results have an application in the product of the company for which the work is done.

RECORDS

The question of the keeping of records of research work is of fundamental importance. If an experiment is worth doing at all, the results, whether satisfactory or not, should be worth recording. The record should be such that no matter how long afterward it is necessary to look it up, there will be nothing obscure in it as to what was done, how it was done, and what result was obtained. Every such record should carry the date and a record of the apparatus and instruments used. It should fit into the general record system of the company for which the work is done and when the work is finished, the complete record should be filed so that it can be readily found. How often do experiments have to be repeated because the observer failed to state in his record something very obvious at the time, as, for example, whether 25 or 60 cycles were used, or what was the constant of his instrument or any one of a score of other things. The experiment may be such that the frequency is of no importance whatever for the result desired, but later developments may be such that, were the frequency recorded, a repetition of the work might be avoided. An exact date may decide whether or not the experimenter is entitled to a patent that may be fundamental. In fact, the coincidence of experimenters working along the same lines at the same time—perhaps thousands of miles apart—has often been

repeated, and an exact date is necessary to prove priority of invention. The record should not be crowded with details that can never have any bearing. Experiments that are of doubtful value due to causes found after the experiment is performed, should be so marked on the record. In short, the work should, if possible, be so carried out that there are no doubtful elements in the test, and the record should be so kept that the experiment need never be repeated.

CONCLUSION

The attempt has been made to so develop the subject that the qualities required in the experiments would be apparent, but the following brief statement may be of interest: The man who is engaged in research work should have a thorough technical training; he should be capable of close observation, should be able to think straight, to draw logical conclusions from experiments performed. He should not discard results because they do not prove preconceived opinions; he should be able to get all the data required or available; he should be able to distinguish the important from the unimportant and not be misled by some minor or interesting ramification of the subject. While he should be capable of framing theories, he should not insist that every test proves his pet theory. He should be judicial; he should be capable of considering the opinions of others; he should not try to account for effects by some abstruse theory when the cause is very simple. He should be capable of working with others in his organization without friction; he should "play the game according to the rules." He should be in every sense of the term a true gentleman.

THE METER AND TESTING DEPARTMENT OF THE HARTFORD ELECTRIC LIGHT COMPANY

F. W. PRINCE,
Superintendent

THE work done by the meter and testing department of The Hartford Electric Light Company comprises all tests in the calibration and adjustment of meters of all kinds, adjustment and maintenance of arc lamps, photometry of all electrical illuminating units, motor characteristics, transformer characteristics and voltage and amperage tests made at the central station or at the customer's premises. This article, however, deals only with the adjustment, calibration, installation, maintenance and reading of recording or integrating wattmeters.

Source of Supply—The meter room is equipped with both direct and alternating-current service, the former being supplied by a three-wire Edison 120/240 volt systems, the later by a two-phase,

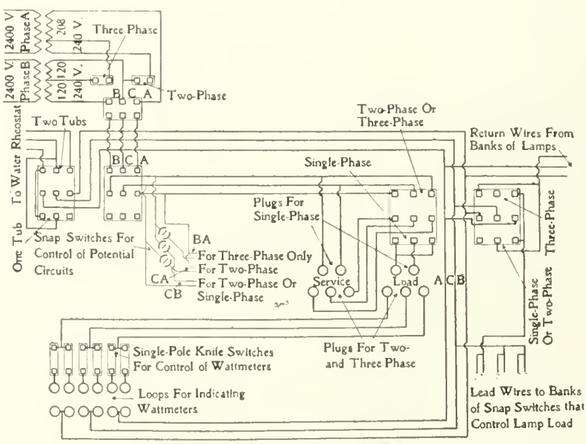


FIG. I—CONNECTIONS FOR TESTING TWO AND THREE-PHASE METERS

2 400 volt system stepped down through two 50 kw transformers to a 120/240 volt three-wire system, on the low-tension side. The transformer secondaries are also provided with taps at 208 volts. In order to afford flexible control, both high and low-tension panels are used, the former being equipped with special plug switches for

safely handling the high voltage and making various combinations of connections.

The low-tension panels consist of an alternating-current panel to which are brought two complete three-wire 120/240 volt systems, one for each transformer and an extra 208 volt wire for use in three-phase combinations. The circuits are shown in the diagrams of connections in Figs. 1 and 2. By means of a number of three-pole switches any desired combinations of circuits can be made to the various meter testing boards. By means of jumper switches the outer wire of phases *A* and *B* can be connected to serve as a power neutral for a two-phase, three-wire, 220 volt system. By means of these switches the phase *A*, 208 volt tap, can be connected

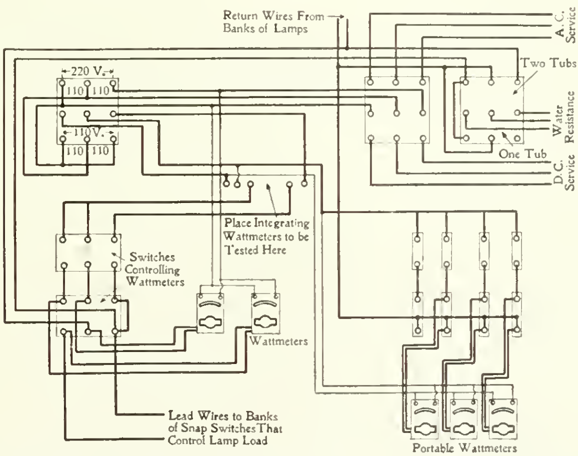


FIG. 2—CONNECTIONS FOR TESTING SINGLE-PHASE AND DIRECT-CURRENT METERS

to the phase *B*, 120 volt tap, thus transforming the two-phase circuit to a three-phase, 220 volt, three-wire system.

By means of a direct-current panel, the three-wire direct-current system is controlled through a main switch, and two separate three-wire circuits are carried to the meter testing boards. Recording voltmeters are permanently connected to the alternating and direct-current circuits, thus giving a continuous record of the voltage regulation maintained on the testing circuits.

METER TESTING BOARDS

There are six meter testing boards, as shown in Figs. 3, 4 and

5, composed of 36 by 60 inch soapstone panels mounted vertically on slate tables. The entire set is mounted on a heavy wooden framework resting on solid brick pillars. By this construction, vibration is eliminated and a solid, permanent structure is secured.

An adjustable support which will accommodate any style of commercial meter, is mounted on the face of each soapstone panel, thus enabling meters of different makes to be quickly connected into circuit. Connections to the meter under test and the standards are made on the front of the boards through taper plugs which have proven more satisfactory than the usual form of binding posts.

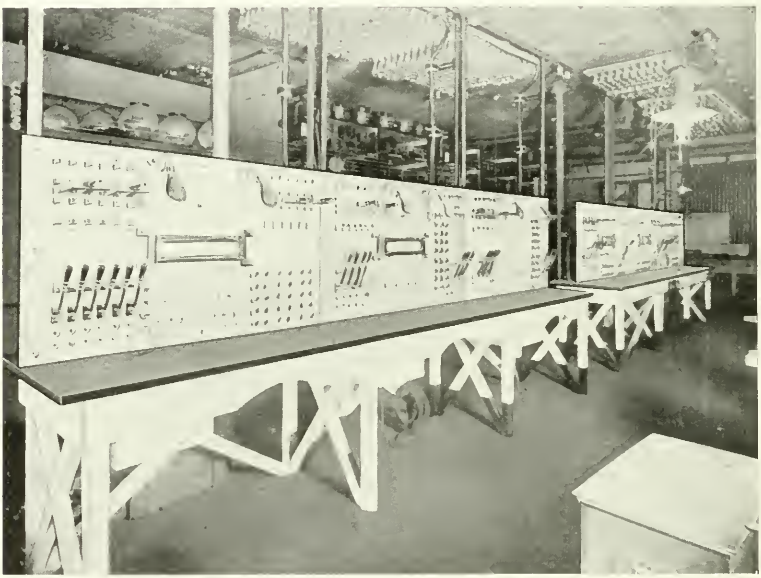


FIG. 3—GENERAL VIEW OF METER TEST BOARDS

To control the loads which consist of incandescent lamp banks, three-pole double-throw knife switches and a number of snap switches are mounted on the face of the boards, so that graduated loads for testing can be readily obtained. One of the double-throw knife switches is arranged to control either alternating-current or direct-current service, a second switch connects either 110 or 220 volts to the meters and a third connects in either of two water rheostats for obtaining heavy loads in excess of the lamp bank capacity.

All switches are back connected, thus keeping the wiring out

of sight and affording safety to the meter testers. The only live wires on the front of the testing boards are the few flexible meter leads consisting of No. 6 and No. 00 rubber covered cables soldered into back-connected, tapered brass receptacles fastened into the face of the boards. To secure inductive loads a variable reactance is arranged for connection in the incandescent lamp bank circuits.

STANDARDS

The testing equipment consists of some fifty instruments of various current and voltage capacities so that meters from the

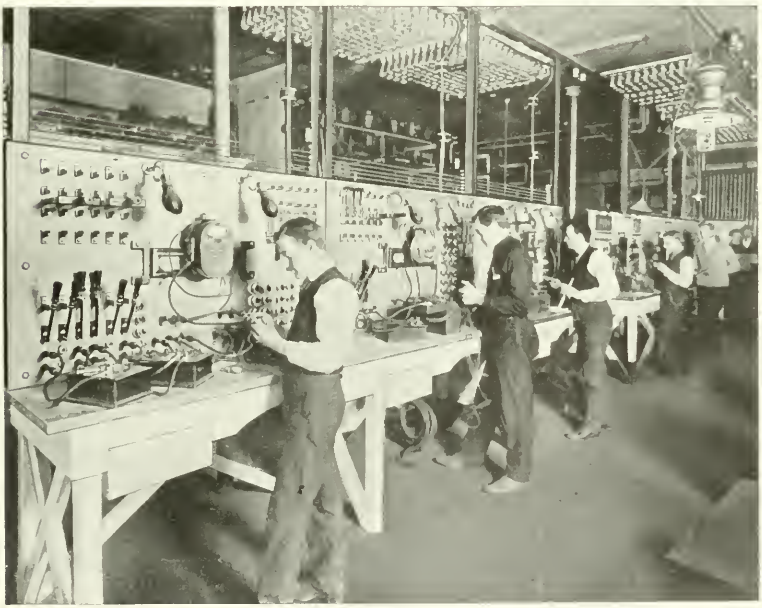


FIG. 4—VIEW OF METER TEST BOARDS IN USE

smallest to the largest capacities can be readily tested. The working standard or testing wattmeters are regularly compared with a "precision" standard wattmeter every six weeks and a complete calibration curve plotted for each instrument. The precision meter is standardized every six months in the laboratory of the manufacturer.

TESTING SERVICE METERS

Every service meter is tested before installation, even though

it has run only a few revolutions in its previous installation. For all meters there is a locus for points on the error curve (Fig. 6) determined by the following table of maximum errors allowable at various load points:

At two percent of full-load—maximum error allowable, six percent either fast or slow.

At ten percent of full-load—maximum error allowable, four percent either fast or slow.

At twenty percent of full-load—maximum error allowable, one percent either fast or slow.

Above twenty percent of full-load—maximum error allowable, one percent either fast or slow.

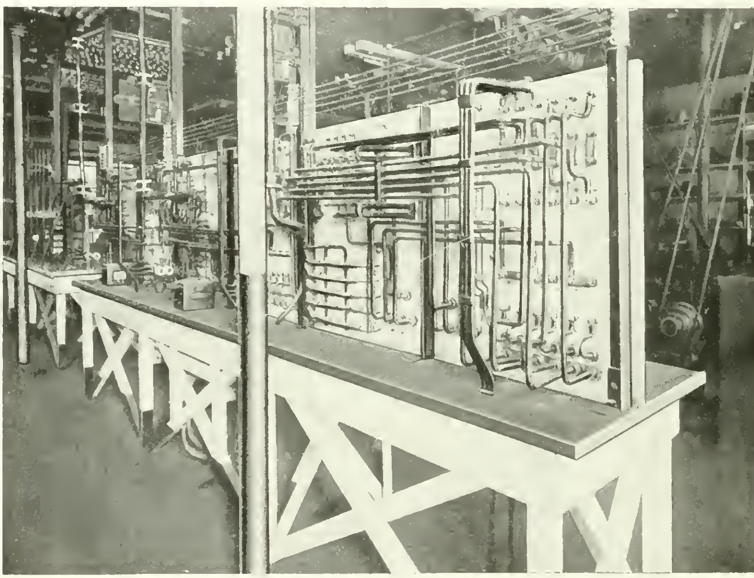


FIG. 5—REAR VIEW OF METER TEST BOARDS

Commutator and polyphase induction meters of capacities up to and including twenty-five amperes are tested and adjusted at the following load points: two percent, three percent, five percent, ten percent, 25 percent, 50 percent, 75 percent and 125 percent. On meters of larger capacity, the two percent and three percent points are omitted. Single-phase induction meters are tested and adjusted only at ten percent and 100 percent load points, experience indicating that proper adjustment at these two points insures a correct curve at all points as the induction meter has a definite characteristic less dependent on the element of friction than the commutator type.

All two-wire, 110 and 220-volt meters are tested with their regular normal connections. For testing three-wire, 220-volt meters, a modified three-wire circuit is obtained by connecting the two outside lines to one side of the two-wire supply mains and the neutral line to the other side. The meters are then tested with the fields in multiple, one series coil reversed and the standard instrument connected in the middle leg, using the normal calibrating constants. All polyphase meters are tested on single-phase, 220-volt circuits with the pressure coils in multiple, the fields in series on one leg, the standard instrument connected in the other leg and using one-half the normal calibrating constant. All meters with series transformers are tested as five ampere, self-contained instruments and their series transformers are checked up with standard ammeters.

Meters in service and which have developed simple or obvious troubles are merely inspected for mechanical stoppages or open potential circuits, and immediately changed. In case of apparent error in accuracy, a portable standard indicating wattmeter is used for testing commutator type meters and a rotating standard for testing induction meters. When possible, service meters are tested on the line at their normal running load and checked up or re-calibrated. This method can frequently be used in residential or suburban districts, but in the majority of cases, if troubles cannot readily be located and repaired by cursory inspection, the meter is brought in to the meter department, re-tested, cleaned, re-calibrated and put in perfect condition before being re-installed.

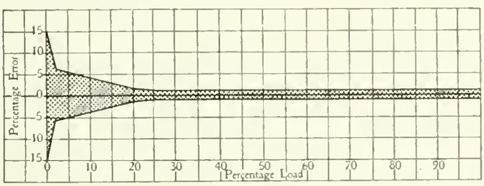


FIG. 6

All meters must be adjusted so that their percentage error curve will be contained in the shaded space shown above.

Upon receipt of a complaint from a consumer, the option is given of having the meter inspected or brought in, as desired. A test of the wiring is made with a magneto to locate grounds or short-circuits, and all results are recorded in the department records and a copy forwarded to the consumer.

To facilitate testing while in service, power loads of five hp and above, have in circuit with them, a loop or "cut-around" switch which

admits of connecting a standard wattmeter in circuit without interruption of service. All such installations are tested at regular periods and any re-calibration necessary is done at that time. By this method all large factory power installations are tested and kept accurate every four weeks, tests being arranged in regular routes so that they occur regularly every month.

INSTALLATION METHOD

Experienced employees of the meter department install the meter on the consumer's premises, deliver the first installation of lamps, screw them into their sockets, make a correct account of all electrical apparatus or equipment on each meter circuit and see that all such apparatus and lamps work properly at the time of installation and that the meter starts to record. Previous to the order for placing the meter, a representative of the inspection department has been to the installation and seen that the wiring is in perfect condition, that no short-circuits or grounds exist, that the meter loop is left so that the meter can be readily connected and that it is located not over eight feet from the floor. In case the meter loop is not ready or the wiring unfinished or unserviceable, the meter man returns with the meter and the customer is notified that the faults must be corrected before the meter can be installed and service given. In order that everything may be in readiness when the final order for the meter is given, the company issues to each electrical contractor, a compact and complete book of local regulations governing the location of service wires, meters, switches, cut-outs, etc.

All meters in service are read regularly each month by employees of the meter department. The reading sheets then go to the accounting department and are immediately billed so that the consumer receives his bill the second day after the reading has been taken. The city is divided into routes and districts, and all meters in each district are billed on the same date each month.

METER RECORD SYSTEM

The card record system and its attendant slips can best be described by tracing the history of the meter from its arrival from the manufacturer through its life until it is cut out and brought back to the meter department. Immediately on arrival, meters are sorted according to capacity, inspected as to condition, stenciled with the company's special serial number, a complete record made, and the meter placed on the stock shelves. An identification card is made

out from the name plate of each meter and filed in the stock drawer until this meter shall be installed. As soon as practicable the meter is then tested and adjusted and a record of final adjustment made on a special form, the record being placed inside of the meter cover, after which the meter is placed on "tested" shelves. When a demand comes for the meter, the test card is removed from the cover, and the name of the consumer on whose premises it is to be installed written on it and on the tag attached to the meter. The employee who installs meters signs this slip and on his return makes record of the meter load, number of lamps, candle-power, horse-power of motor load, etc., after which the slip is complete and ready for copying for file in the record case. A reading sheet for this meter is also made out and filed in the proper route file, while the record card is properly filed by location in a large cabinet. The identification card has the location recorded on it and is taken out of a "Stock" drawer and filed by number in a "Service" drawer.

The meter is then regularly read and billed by the office force until some complaint comes in, when it is inspected by a meter inspector, who records on a special form the condition of the meter, the result of this inspection then being recorded on the record card. In case the meter is brought in for re-test, the results of this test and the date when it is re-installed are recorded.

When a service is discontinued, the meter is cut out and the employee makes out a slip with the name and location of the consumer and the reading of the meter, this information being placed on the record card and the reading on the reading sheet. The record card is then taken from the main cabinet and refiled under "Meters Cut Out." The identification card has the "cut out" recorded on it and is taken from the "Service" drawer and replaced in the "Stock" drawer until such time as the same meter is re-installed. All meters are regularly inspected in place once a year, and a certain number are regularly brought in for re-test every year. Necessary repairs and results of tests are recorded on the record cards.

The meter department at present is handling about forty meters a day, making new installations, making changes, re-installing after re-tests, and cutting out meters. About thirty-six tests are made each day, such as first tests for meters brought in, second tests on meters removed from service, etc. The daily reading routes comprise about three hundred meters, special readings and inspections.

RAILWAY CALCULATIONS

MALCOLM MacLAREN

A NUMBER of articles have appeared in the JOURNAL giving methods for calculating the performance of railway equipments under service conditions. It is possible, however, that the degree of accuracy with which a service may be pre-determined is not very generally understood, and the following illustrations, taken from tests made on the New York, New Haven & Hartford Railway, are given to show the close agreement which exists between theory and practice.

It is usual in these calculations to simplify the work by substituting for the irregular profile of the road a uniform grade equal to the average grade between terminal points; if curves are not sufficiently severe to require slow-speed running, the effect of these is also

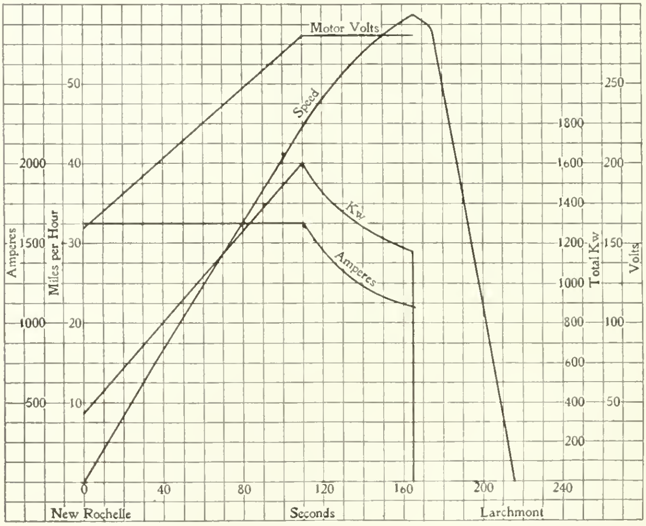


FIG. I

averaged, and instead of figuring out each individual run for a train making frequent stops, the service is studied by a single typical run equal in length to the average distance between stops. Some discretion has to be used in applying this method, as it would not hold good over too wide limits, but with proper precautions it will give accurate results.

By applying this method to a study of the local service on the electrified zone of the New Haven system, it was found that the average grade between Mt. Vernon and Stamford is a little less than one-tenth percent. The average distance between the stations is 1.65 miles, the individual runs varying from 0.4 of a mile to 2.62 miles.

The curves do not materially affect the speed of the local trains and they need not be considered. From a series of tests made upon trains operating in regular service, the running time from Mt. Vernon to Stamford for 200-ton trains, when the time between station stops averages 45 seconds, is found to be 47 1-3 minutes, and from Stamford to Mt. Vernon 48 2-3 minutes. The typical runs in the two directions were calculated, using an accelerating current equal to the average obtained in the tests, and taking a braking rate and period of coasting to correspond as closely as possible to the values obtained in service. The running times as obtained in this way were 47½ minutes from Mt.

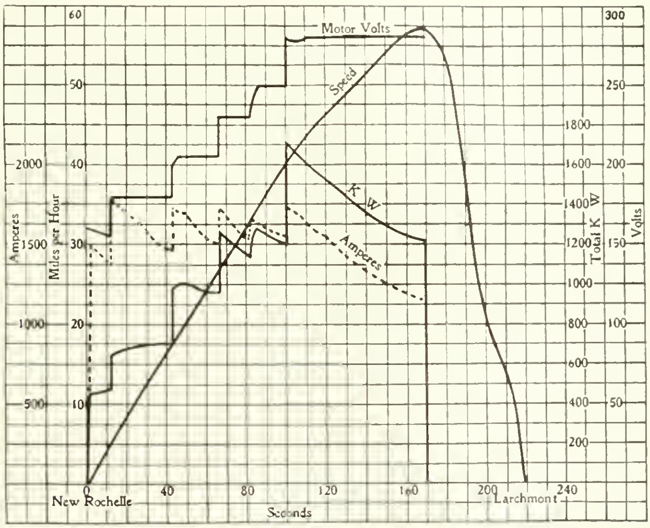


FIG. 2

Vernon to Stamford, and 49 minutes from Stamford to Mt. Vernon. The calculated and measured values for heating current and power consumption showed equally close agreement.

The theoretical studies of individual runs, as made during the preliminary calculations, also check closely with results obtained from tests on the locomotives in service. The calculated and test performance of a locomotive, when hauling a 296-ton train between New Rochelle and Larchmont, a distance of a little over two miles, are shown in Figs. 1 and 2. On comparing these curves, it will be found that during acceleration, the speed curves are practically identical up to 40 miles per hour. At the higher points, the calculated speed is

slightly higher than the test speed, apparently because a lower train resistance was assumed than that actually obtained. The net result of this error is to make the calculated time of the run three seconds shorter than the actual, or 216 seconds instead of 219 seconds. To facilitate the calculation it was assumed that the voltage is increased uniformly during acceleration instead of by steps, as actually occurs with unit switch control. This accounts for the difference in the character of the voltage, current and power curves in the two cases. No appreciable error, however, is introduced by this assumption. The square root of the mean square current per motor, which determines the heating of the apparatus, was 1 210 amperes, measured, and 1 200 amperes calculated. The power consumption for the run, including the transformer losses, is 66.5 watt-hours per ton mile measured, and 64.2 watt-hours per ton mile calculated. The power required for this run while fairly low for such a service is higher than that usually obtained on the New Haven system. The reason for this is that the current was held on up to the time of applying the brakes, whereas it is usual to allow considerable coasting.

Fig. 2 further shows the remarkable steadiness of the line potential. The tests show that even at the extreme end of the line, 18 miles from the power house, the line drop does not amount to ten percent at the time of heavy traffic. This run is characteristic of the performance of the locomotive when hauling these heavy trains. The starting currents which are used daily are from 50 to 75 percent in excess of the normal full-load current, and in addition to this a motor voltage of over 25 percent above the normal is frequently applied. This latter possibility is of special interest and is one of the unique features of the single-phase system. It is well known that with a direct-current motor, the armature losses rapidly increase with the increase of voltage. This is not necessarily the case with the single-phase motor. Advantage of this was taken during the development of the New Haven locomotives and the transformers and control were arranged to give two over-voltage running points. On account of the large over-load capacity of these locomotives they are able to haul 300-ton trains on the shorter runs out from New York, whereas the maximum weight of train which the locomotives were guaranteed to haul on the local service was 200 tons. The principal function of the higher voltage points is to enable these heavier trains to be operated without loss in schedule speed and to provide a liberal margin for making up time in case of delays.

The performance of the same locomotive on the run from Wood-

lawn to Mt. Vernon is shown in Fig. 3, in which section the transition from direct to alternating current is made. It may be seen that the time required for passing from one system to the other is only 20 seconds. The speed of this particular train was checked by the signal at Woodlawn, so that the transition point was passed at comparatively low speed. The change from direct to alternating current and vice versa is ordinarily made when running at 40 or 50 miles per hour.

It should not be assumed from the above that the operation of trains can be reduced to an exact science or that the time for any run and resulting load upon the apparatus can always be pre-determined

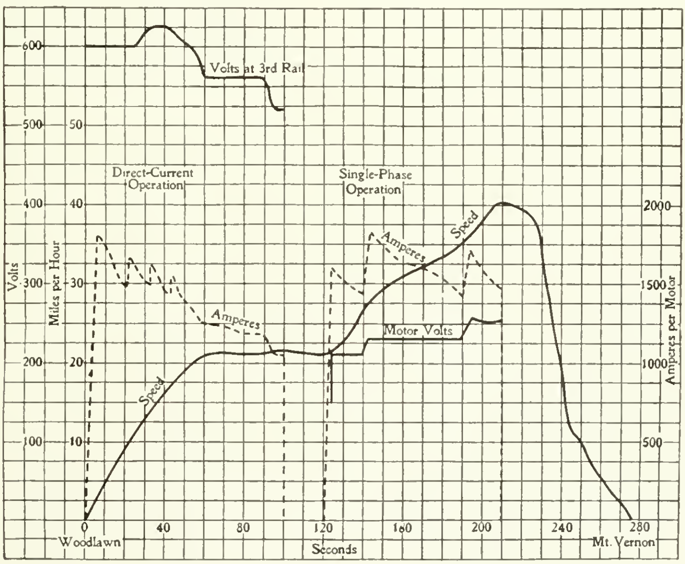


FIG. 3

within the limits indicated above. There will often be incidental delays due to various causes, such as high winds, signal stops and variations in time of stops at station so that, in selecting an equipment for a given service, this fact must be recognized and proper allowance provided for making up time in case of delays. The examples which have been given, however, show that if the conditions of operations are specified, the actual performance of an electrical equipment on a given service can be pre-determined with considerable accuracy and in most cases this can be done without making very elaborate calculations.

CIRCUIT-INTERRUPTING DEVICES—V (Concl.)

CARBON-BREAK CIRCUIT BREAKERS

F. W. HARRIS

OPERATION

The carbon-break type of circuit breaker was designed primarily for use on switchboards, and such types are generally not as well suited to industrial use. Circuit breakers on switchboards are subject to frequent use, are generally located in a clean place and are handled by a good class of labor. When used with motors, the conditions are much more severe and therefore, circuit breakers that are very satisfactory on switchboards sometimes fail in industrial service. The fuse is also an active competitor and its cheapness, as well as its desirable time element, makes it preferable in many cases. Also a fuse and switch are "full automatic," i. e., the switch must be opened for fusing and when it is closed on an overload, the fuses blow. Fuses, however, cannot be made to open all lines at once nor can they be arranged for underload or other variation. Further, they introduce some fire risk and are expensive to replace.

Multipolar Operation—It is highly desirable to have circuit breakers so installed as to entirely disconnect the apparatus to be protected. In the case of direct-current circuits a single-pole circuit breaker is often installed, the other line being connected by a switch. In the same manner a two-pole circuit breaker may be used on polyphase alternating-current circuits. The Underwriters Rules specify that circuit breakers must disconnect all lines. This ruling is somewhat hard to reconcile with the fact that fuses and breakers may be used interchangeably as far as the rules go and no such construction is possible with fuses.

Full Automatic—The ideal multipolar circuit breaker would be "full automatic," i. e., all poles would close together and open together upon trouble on any one of the lines of the circuit, regardless of the position of the operating handle. Such a design requires two toggles and a latch, or one toggle and two latches and, in the case of carbon-break circuit breakers, complicates an already complicated device.

In the absence of such a design, the same result may be accomplished by the use of a multipolar switch in series with a circuit

breaker, like that shown in Fig. 12, in which all the poles close together and open together on the occurrence of trouble on one of the lines. The cost of the switch and the additional space makes such an application more expensive. In this type of circuit breaker the handle levers are inter-connected by cross-bars. When one of the poles of the circuit breaker trips, the force of recoil works through this cross-bar to trip the other poles. In the type shown in Fig. 13, the moving armatures are connected to move as a unit and all latches are tripped at once.

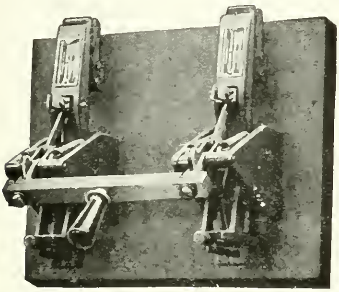


FIG. 12

Hand Trip—A ready means must always be provided for opening circuit breakers by hand. This is commonly a small knob on the armature or a latch, but a better way is to cause the operating handle to trip the latch when the handle is moved in a direction opposite to that used for closing. If the latter method is used, provision should be made for a "snap break."

Recoil—A considerable blow results from the sudden opening of circuit breakers. This must be absorbed and the preferable way is to provide friction jaws. Soft rubber bumpers or spiral springs are also used, but there must be no rebound. Soft rubber is undesirable, as it is not permanent.

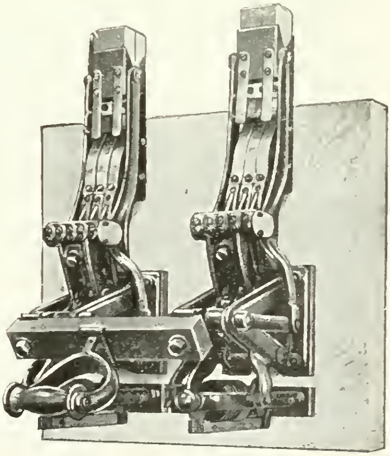


FIG. 13

Under-voltage Release — The requirement that the circuit breaker shall open upon failure of the source of supply is a very common variation. This is accomplished by connecting a coil or coils across the source of supply and so arranging the mechanism that releasing the armature of these coils opens the circuit breaker. As the coil must stand full voltage continuously, a resistance is often used in series so that a reasonable size of wire may be used. To get perfect protection, there should be a coil for each phase

on alternating current, but such protection is not absolutely necessary and often only one coil is provided.

No Field Release—Coils may also be furnished to connect in series with the field of a motor or generator so that a failure of excitation will open the circuit.

Under-load Release—A similar device is the under-load release in which the main current of the circuit breaker passes through the coils, the failure of current in which will open the circuit.

Shunt Trip—Circuit breakers are also commonly furnished with a coil arranged to operate the trip. This coil may be actuated by a push button, a relay or another circuit breaker. Coils are designed to be in circuit only momentarily, the opening of the circuit serving to disconnect the coil. Where this cannot be provided for a small switch may be used (see Fig. 14) and so arranged as to open with the circuit breaker. This switch may also be arranged to close the tripping circuit of another circuit breaker, thus interlocking them. A switch may also be arranged to ring bells, light lamps, etc.

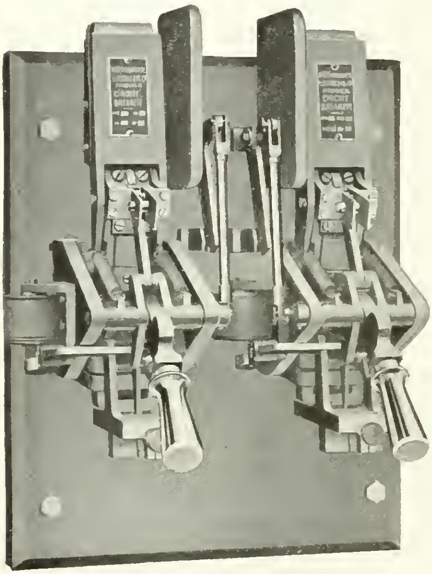


FIG. 14

Reverse Current—When it is desired to protect against a reversal of current, a small reverse current relay is used to actuate the shunt trip.

Over-voltage—In a similar manner an over-voltage relay may be used where protection against excessive voltage is required.

Combinations—Many cases arise in which it is desirable to have combinations of two or more features. It is very common to build circuit breakers to operate on over-load and no-voltage and often the under-load feature is required in addition. Fig. 15 shows an over-load, no-voltage, shunt-trip circuit breaker.

Electric Operation—While the demand for electrically-operated

oil circuit breakers is large, the demand for electrically-operated carbon-break circuit breakers has been comparatively small. Non-automatic circuit breakers for use with the automatic synchronizer (See Fig. 16) and full automatic circuit breakers (See Fig. 17) have been developed, however, in larger capacities; that shown in Fig. 18 being used to close equalizer circuits. In an electrically-operated circuit breaker of this type, provision should be made for a no-voltage release mechanism and the whole device should be compact and complete.

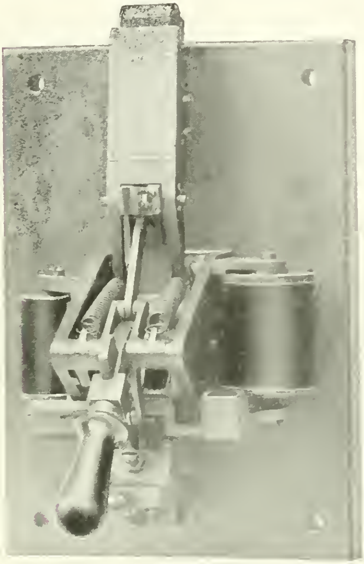


FIG. 15

Remote Mechanical Control—As in the case of oil circuit breakers, carbon circuit breakers may be operated through lever systems. Such a requirement, however, is rare.

Heating—Carbon-break circuit breakers are required to carry their rated load with a maximum rise in temperature of 20 degrees C. Like most devices they will carry 150 percent of the rated load at approximately double the rise, or forty degrees C. It is thus seen that if the circuit breaker is calibrated from eighty percent to 160 percent of the full-load, it will not heat excessively on any setting.

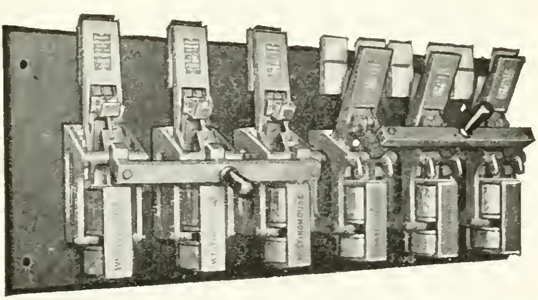


FIG. 16—THREE-POLE ELECTRICALLY OPERATED CIRCUIT-BREAKERS

Insulation —The handle for operating the circuit breaker should be thoroughly insulated from all live parts. In one type of circuit breaker the frame is insulated from the brush, etc., but this does not seem necessary as switches are manipulated much oftener and no such insulation is provided on them.

Moreover, such insulation is not very reliable and it may deceive the operator into trusting it, with serious consequences. Circuit breakers should, in general, stand an insulation test of 2 000 volts for one minute between poles and between studs with the brush in the open position.

Life—Endurance tests are rarely called for on circuit breakers. Their life is more or less a function of price. The cheapest of them should open under normal conditions a thousand times without being seriously injured and a first-class circuit breaker many times this number.

Opening Short-Circuits—The heavier types of circuit breakers are very reliable, but heavy short-circuits represent tremendous energy when they occur with low resistance and high generator capacity. Such short-circuits are not frequent, however. The first function of a circuit breaker under such conditions is to open preferably without injury to itself, but in any case, to open the line. The better designs will open such abnormal conditions many times without injurious effects. In very heavy short-circuits there is a decided magnetic blowout effect as the arc becomes a section of a closed loop and tends to spread upward and outward and then rupture. The tendency of hot air to rise greatly assists this action.

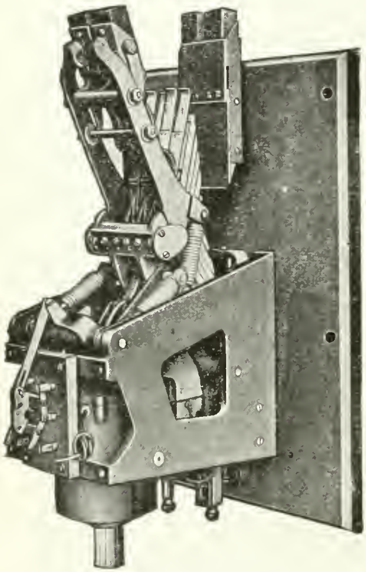


FIG. 17

INSTALLATION AND CARE

Location—Circuit breakers on which excessive short-circuits may occur, such as main circuit breakers fed from heavy busses, should be so placed that the arc and hot vapor due to their opening can do no harm. The best place for such apparatus is at the top of the switchboard with the carbons projecting above the upper edge. Secondary circuit breakers of small size for feeders, etc., may be placed on the face of the panel. A switchboard with a large number of such circuit breakers is shown in Fig. 19.

Connections—Great care should be exercised in making connections to bus-bars, especially when adapters are used. As these connections are very close to the main contact of the circuit breaker, and as the studs are of copper, which is an excellent conductor of heat, a poor connection is often to blame for alleged heating of the contacts. This connection should always be carefully looked into when trouble exists.

Brush Adjustment—The laminated copper brush is a fruitful source of trouble and not easy to adjust. It should bear evenly throughout its surface and with considerable pressure. A brush print that will show a poor contact, if it exists, may be obtained by inserting a piece of white paper between the brush and the block and then closing the circuit breaker. Care should be taken to see that the carbons are in firm contact until after the main brush is out of contact. Inasmuch as the opening and closing of the apparatus keeps the contacts bright by the scouring action of the brush, it is not necessary to clean the brush surfaces on circuit breakers in frequent use. Where they are opened infrequently, e. g., once a day or less, especially in smoky or dusty locations, this infrequent opening is not sufficient to keep the contacts bright. The oxydizing of surfaces will then produce local heating, which oxydizes the contacts still further with the result that the brushes get very hot. Under such conditions brushes should be brightened up with emery cloth once a week or oftener.

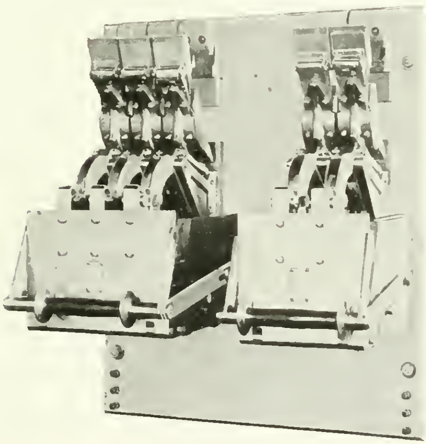


FIG. 18

FUTURE DEVELOPMENTS

The carbon-break circuit breaker as now manufactured is a fairly well developed device. The fact that all commercial circuit breakers follow certain fundamental points of design shows plainly that these are necessary and that improvement of these general es-

sential features is not probable. In the matter of minor details and particularly in the matter of reducing cost much can yet be done.

As regards operation the principal need seems to be the production at a reasonable price of a circuit breaker which will be mechancally strong particularly as regards the contacts. There is a tendency with designers of detail apparatus to produce apparatus which is mechanically weak due largely to the influence of the smaller details such as sockets, snap switches and all such articles commonly classed as "supplies." While there will always be a demand for

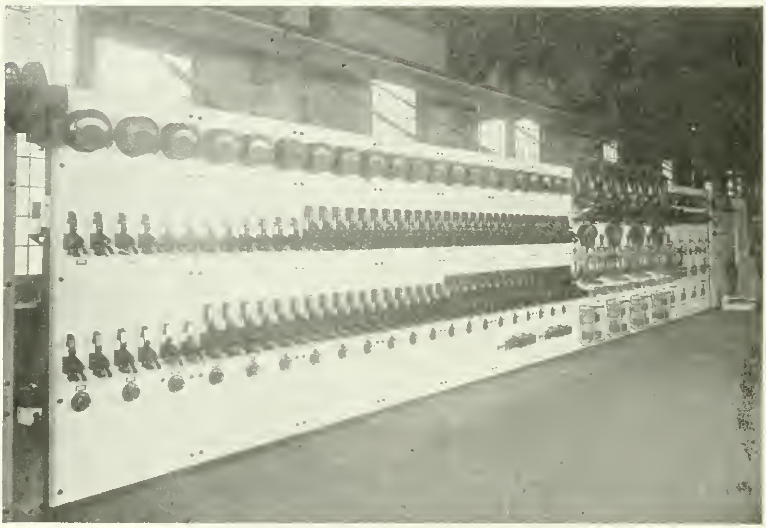


FIG. 19

such cheap designs there is a great field of industrial business such as rolling mill and general factory service in which reliability is the main point. Where such reliability can be demonstrated a corresponding increase in price is not objectionable. There is no doubt that improvements along this line are possible. There is a probability however that such designs would include magnetic blowouts and omit carbon arcing tips. Oil circuit breakers also become more and more important as cost increases.

THE PROTECTION OF ELECTRIC CIRCUITS AND APPARATUS FROM LIGHTNING AND SIMILAR DISTURBANCES (Concl.)

R. P. JACKSON

DIRECTIONS FOR SPECIFYING LIGHTNING ARRESTERS AND CHOKE COILS

LIGHTNING ARRESTERS

Practically all plants with outdoor circuits require lightning protection. With reference to the type of lightning protection required, electric plants may be divided into two general classes, those plants in which the apparatus is widely distributed, and those in which the apparatus is concentrated at a comparatively few points.

Plants Having Apparatus Distributed—To obtain absolute protection, arresters must be placed at all points where apparatus is located. Experience has shown, however, that in certain cases such a large number of arresters is unnecessary.

In circuits not exceeding 2 500 volts, it will usually be sufficient to place arresters at various intervals where good grounds are available. These arresters should be so placed as to leave no considerable length of circuits (electrically speaking) unprotected, and should be most numerous in neighborhoods where the circuits are most exposed. These neighborhoods are more likely to be the outlying districts where the lines are not protected by buildings and trees. The exact number to be used in any given case depends on circumstances; under average conditions, satisfactory protection will be secured if no point of the circuit is more than 1 000 feet from an arrester.

Plants Having Apparatus Concentrated at Few Points—In plants with apparatus concentrated at a few points, which is practically the case in all high tension work, one arrester should be used for each line wire, at or near each point where apparatus is connected to the circuit.

For all circuits with ungrounded neutrals, arresters rated at the voltage between line wires should be chosen; that is for the maximum working voltage and not for the voltage between line and ground. This method insures the arrester against arcing when one side of the circuit is accidentally grounded.

If the circuit has a grounded neutral, arresters chosen for a voltage 20 percent greater than the maximum voltage between line and ground will have ample margin for protection. For example,

for a three-phase Y-connected circuit with grounded neutral and having 16 500 volts between line and ground (approximately 28 000 volts between line wires), arresters for 20 000 volts should be chosen.

In selecting alternating-current lightning arresters for a given service, both the electrolytic and the multi-gap arresters are chosen solely with reference to the voltage of the line on which they are to be used, and not with reference to the current.

INSTRUCTIONS FOR INSTALLING MULTIGAP LIGHTNING ARRESTERS

Insulation—A lightning arrester is exposed to severe potential strains and therefore all active parts must be well insulated. It is not a difficult matter to secure proper insulation of low-voltage arresters since the construction of the arresters themselves affords protection; on high-tension arresters, sufficient insulation is a more difficult matter. Low-equivalent arresters are marble mounted, and while this marble affords sufficient insulation on low-potential circuits, in order to obtain the further insulation necessary on circuits exceeding 6 000 volts, panels are mounted on shellaced wooden supports. On circuits exceeding 12 500 volts, the arrester panels should receive additional insulation in the form of porcelain or glass insulators, which are furnished with low-equivalent arresters. In installing an arrester, it should be assumed that all parts of the resistance except the ground terminal of the series resistance may be momentarily at line potential during the discharge. Two high tension arresters attached to different line wires should not be placed side by side without either a barrier or a considerable insulation space between them. The resistance, which during the discharge may be subjected to full line potential (except the ground end of the series resistance) must be spaced or insulated as well as the line.

The space between active parts of adjacent arresters connected to different sides of the circuit should not be less than the distance designated in the following table:

Voltage		Distance Between
Exceeding	Not Exceeding	Active Parts in Inches
5 700	8 500	6
8 500	12 500	7
12 500	18 000	9
18 000	25 000	12
25 000	29 000	15
29 000	37 000	20

Setting Auxiliary Gap—The auxiliary gap allows the margin over the normal voltage, required to break down the series gaps, to be adjusted to suit individual lines. In addition to the actual variations of potential to be taken care of in systems using the same design of arrester, such an adjustment is necessary on high voltage circuits, since even on two systems nominally at the same voltage a different number of series gaps may be required to hold the normal voltage. This condition is due largely to difference in capacity of the line and in the wave form of machines, but is influenced also by the location of the arrester with reference to surrounding objects, as well as by some other conditions.

GROUNDS FOR LIGHTNING ARRESTERS

Too much importance cannot be attached to the making of proper ground connections, which should be as short and straight as possible from the arrester to the earth. A poor ground connection will render ineffective every effort made with choke coils and lightning arresters to drive the static electricity into the earth. It is important, therefore, not only to construct a good ground connection, but in doing so to appreciate thoroughly the necessity of avoiding unfavorable natural conditions.

The question of a suitable ground connection for lightning arresters or the various other purposes for which an earth connection is required is one much disputed or discussed. A convenient and inexpensive form of ground may be obtained by burying an old iron casting. The connection should be securely bolted or riveted to it so that the contact will not become impaired by rust or corrosion. Also, a large copper cable, say 1 500 000 cir. mils, about three feet long with a lead sweated to its middle portion and its two ends fanned out in semi-circles will make a ground plate of very large area for the amount of copper it contains.

What might be called standard specifications for a ground connection are as follows:

First, dig a hole four feet square directly under the arrester until permanently damp earth has been reached; second, cover the bottom of this hole with crushed coke or charcoal (about pea size); third, over this lay ten square feet of tinned copper plate; fourth, securely solder or rivet to this ground plate a wire, preferably No. 0 copper, across the entire width of the plate; fifth, cover the ground

plate with two feet of crushed coke or charcoal, and sixth, fill the hole with earth, using water to settle it.

The above method of making a ground connection is simple, and has been found to give excellent results, and yet if not made in proper soil it will prove of little value. Where a mountain stream is conveniently near, it is not uncommon to throw the ground plate into the bed of the stream; this practice results in poor ground connections owing to the high resistance of pure water and the rocky bottom of the stream. Clay, even when wet, rock, sand, gravel, dry earth and pure water are not suitable materials in which to bury the ground plate of a bank of lightning arresters. Rich soil is the best. It is therefore advisable before installing a bank of choke coils and lightning arresters to select, with reference to a good ground connection, the best possible site for the lightning arrester installation. Where permanent dampness cannot be reached, it is recommended that water be piped from some convenient source to the ground.

Where possible, direct connection to an underground pipe system, especially of a town or city water main, furnishes an excellent ground, on account of the great surface of pipe in contact with the earth and the numerous alternative paths for the discharge. In a water-power plant, the ground should always include a connection to the pipe line or penstock and to the case or frame of the apparatus to be protected. This is of importance, as, if such apparatus happens to be partially insulated from ground, the effectiveness of the lightning arresters may be materially diminished at the time of discharge.

Inspection—As the effectiveness of the arrester is of great importance, it should be inspected from time to time and the resistance and earth connection tested for open circuit.

CHOKE COILS

Choke coils are not in any way a substitute for lightning arresters, but are an effective adjunct to help the arrester in performing its function. For the protection of generators for any voltage, choke coils of the next higher voltage rating should be used. This selection is made not for purposes of obtaining higher insulation, but simply because generators need, in general, a higher degree of protection than transformers, and coils of the next higher voltage rating have an increased number of turns, thus giving higher protection.

For voltages above 25 000, regular oil-insulated coils, such as shown in Figs. 14 and 15 are preferable.

LOCATION OF CHOKE COILS

Choke coils are ordinarily used in such a way that one coil and one arrester are used on each wire of an incoming line. The rule is not absolute, however, since if a number of transformers is connected in a bank to one line, it is preferable to put choke coils in the leads of each transformer, while but one set of arresters should be used on the incoming line. This arrangement gives better protection for a given drop due to the choke coils than would be possible with one set of large coils in the line. Moreover, choke coils are more effective if placed in the leads from the transformers or generators and inside the switches, so that protection is secured from switching; the surges set up by switching, though usually causing little stress at low voltages, may become dangerous on high-tension circuits.

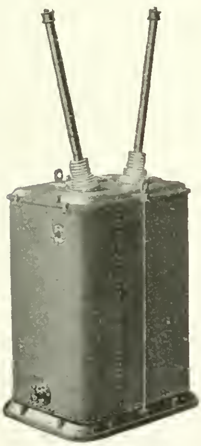


FIG. 14 — OIL-INSULATED CHOKE COIL

With one exception, the choke coil is to be regarded as a part of the apparatus protected, and not a part of the line. The exception is that when two or more transformers are banked and used as a unit, a coil may be used in each lead from the bank. In this case, with a live circuit, the switches between the individual transformers in the bank may be operated with safety only under the following conditions:

1. The opening of a heavy load or a short-circuit will cause no static stress since the change of potential is not sufficiently sudden; but opening the charging current of the line is not permissible.

2. High-tension switches between individual transformers may be opened and closed provided the transformers are in multiple on the low tension side, as under these conditions high tension switching causes no appreciable change of potential. This fact will usually allow connecting, or disconnecting of transformers from the line; that is, to connect a dead transformer in circuit, first throw the low tension winding in multiple with a transformer already excited; then connect the high-tension winding in multiple, after which the low-

tension windings may be separated if desired. In disconnecting a light-loaded transformer from the circuit, first see that the low-tension winding is in parallel with some other live transformer, then disconnect the high-tension winding. The low-tension winding may then be cut out. Where there is no transformer available for exciting the low-tension winding, the transformer may usually be started by first making the line dead and bringing both the line and the transformer up together. Similarly with disconnecting.

3. In filling the case with cold oil, the proper oil level is indicated by the gauge on the inside of the case marked "Oil level cold."

4. The oil level for choke coils should be maintained between the maximum and minimum points indicated on the oil-level indicator on the top casing.

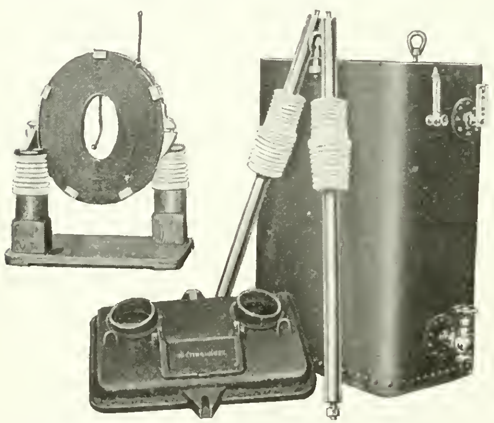


FIG. 15—PARTS OF OIL-INSULATED CHOKE COIL

5. Choke coils should be so placed that air for cooling purposes will have reasonably free access.

6. Cores, cases and low tension windings of transformers protected by choke coils should be grounded through a short spark gap.

7. No switching of live high-tension wires should be allowed between the choke coils and the transformers except that a transformer may be cut in or out on the high-tension circuit, provided voltage be maintained on a high-tension winding by exciting current in the low-tension winding, as previously described. Such switching causes no change of potential in the high-tension circuit.

8. When switches or fuses are used in leads of transformers to provide for alternative delta, or V-connection, all switching between choke coils and transformers may be best avoided by providing line switches outside the choke coils; other methods, however, may be used.

9. When a group of choke coils protects several banks of transformers running in multiple, at least one bank of transformers must

always be in circuit with the coils before connecting them to line.

SAFETY SPARK GAPS

With transformers having large ratios of transformation and operating on high voltage lines, there may occur, on the low-tension side, momentary voltages to ground, greatly in excess of the normal potential. These momentary increases in voltages between the low-tension circuits and ground are commonly called "static disturbances," and in general are the result of a change in the static balance of the high-tension side and its connecting circuits. Unless certain precautions are taken, this static disturbance on the low-tension side may cause serious stresses in the secondary insulation of a transformer with a high ratio of transformation. The induced static voltage is independent of the ratio of transformation; the static stresses are more serious in a high ratio transformer simply because the insulation of its secondary is less able to withstand them.

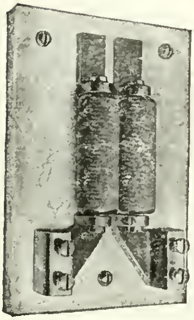


FIG. 16—SAFETY SPARK GAP

For use on low tension side of transformers up to 1 000 volts.

A method of relieving this disturbance is to connect a discharge spark gap (Fig. 16) between some point of the low-tension side of the transformer to be protected, a middle or neutral point if one is available, and the ground. The spark-gap opening is such that any voltage very much in excess of the maximum normal will cause a discharge to ground, and thus the low-tension side is practically tied to ground during such disturbance, while at other times it is ungrounded.

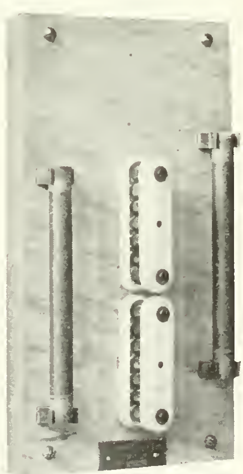


FIG. 17—SAFETY SPARK GAP FOR 2 200 TO 3 300 VOLT SERVICE

When transformers are worked in groups for polyphase transformation it is possible to get into trouble by improperly connecting the discharge gaps to the group. The groupings commonly employed and the spark-gap connections, are shown in Fig. 18. The low-tension windings only are shown, as the connection of the high-tension windings is in general immaterial. It will be noted that only one spark-gap is used in all the groups ex-

cept that of the two-phase independent circuit, which is really two independent single-phase circuits.

The Underwriters recommend the grounding of the neutral point of low-tension circuits when the conditions are such that the maximum normal voltage between the point connected and ground will not exceed 250 volts. This means that one side of a 250-volt circuit or the middle point of a 500-volt circuit may be grounded. For potentials above 500 volts and not exceeding 6 600 volts, a safety gap should be used in the ground connection. This advice applies to transformers whose ratio of transformation is five to one or greater. It is, of course, necessary to have the safety gap set for the particular circuit on which it is to operate, for obviously the setting of the gap on a 700-volt circuit should be different from that on a 2 000 volt circuit.

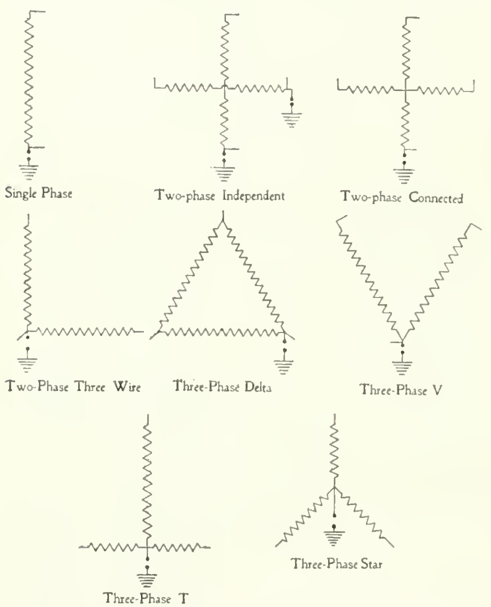


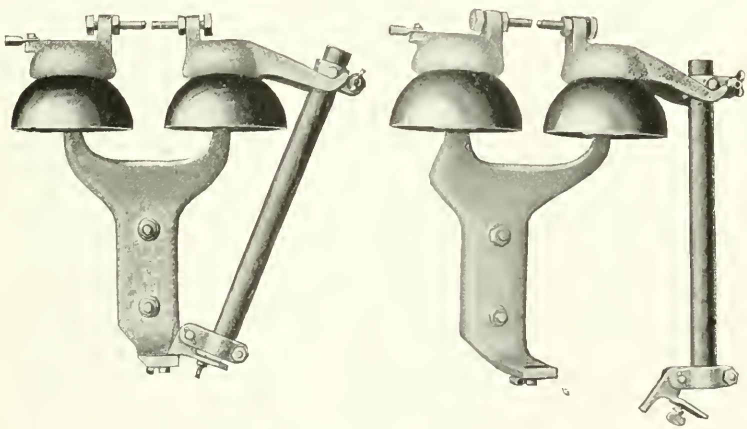
FIG. 18—CONNECTION DIAGRAM FOR SAFETY SPARK GAPS USED WITH VARIOUS ARRANGEMENTS OF TRANSFORMERS

FUSE-TYPE LIGHTNING ARRESTERS

The fuse-type lightning arrester affords a cheap, simple and effective protection to single-phase trolley lines against the effects of lightning discharges or other high potentials. The high voltages employed in the single-phase power transmission system render the use of abundant protection against static discharges imperative. Line feeders, however, do not require such careful protection as do the lines between transformer sub-stations and the cars. For this reason, lightning arresters should be so placed that they will drain the trolley wire of all dangerous static charges, so as to protect the cars. To do this it is necessary that the arresters be placed at frequent intervals along the track, so that a car is never farther than 1 000 feet from a protecting device.

Construction—The fuse-type lightning arrester consists, as shown in Figs. 19 and 20, of a Y-shaped casting as a base, with porcelain insulators mounted at the extremities of each of its arms. On one of these insulators is placed that side of the spark-gap which connects to the line while the other carries the ground side of the gap and the lignum vitae fuse tube, the latter hanging in a sort of trunnion formed by two horns which project from the iron frame of the gap. At the bottom of the fuse tube is a trigger with a finger that projects through a hole in the base casting. The trigger is retained in position by the fuse to which it is attached by means of a thumb screw.

The fuse, which should be of about No. 25 wire, is carried from the trunnion clamp, at the top of the tube, where it is secured by a



FIGS. 19 AND 20—FUSE TYPE LIGHTNING ARRESTER WITH FUSE IN POSITION AND AFTER BLOWING

thumb screw, through the tube to the trigger at the base. When the fuse blows, the trigger at the bottom is released and the tube swings out to a vertical position, thus indicating that a new fuse is needed. The tube may then be removed from the trunnion with a pair of wooden fuse tongs, a new fuse inserted and the tube replaced.

Advantages and Disadvantages—The fuse type arrester has the advantages that it is simple, cheap and does the work without the danger of permanently grounding the line. The resistance of the path for the discharge current to pass to ground is low enough to keep the line potential from rising to a dangerous point, and, at the same time, the blowing of the fuse prevents permanently grounding the trolley wire and thus short-circuiting the line through the arc

across the gap. The spark-gap is adjustable by means of screw terminals, which can be fastened in any position by means of lock nuts.

The principal disadvantage of the fuse-type arrester is that after the fuse blows, the arrester is useless for further service until the fuse has been replaced. On this account it is necessary to use a sufficient number of arresters to prevent them from all being blown in one storm, and then to inspect them regularly. This disadvantage, however, is not peculiar to the fuse-type arrester, since few arresters, in giving the desired protection, are free from the necessity of frequent inspection.

Mounting—The arrester should be mounted on the pole high enough to be out of reach except by using the fuse tongs. One side cf the spark-gap has a terminal for the wire that leads up to the trolley wire. At the lower end of the base casting is another terminal for the wire that leads to ground. This wire should be attached to a rail of the track, since this gives the best ground available, provided the rails are in actual contact with permanently damp earth. With T-rail track construction and stone ballast, or where the surface soil becomes dry or the rails are in only occasional contact with the earth, a very considerable length of rail may have to be traversed before a good ground is reached. Under such conditions it is important that each arrester be provided with a permanent ground, such as described above, to which both the arrester and rail are connected.

PROTECTIVE RELAYS (Cont.)

M. C. RYPINSKI

ALTERNATING-CURRENT OVERLOAD—POLYPHASE

INVERSE TIME ELEMENT ACTION

This type of relay is used for overload protection of feeders and the alternating-current side of rotary converters. It is used chiefly in the polyphase form with inverse time element action and adjustable overload and time element settings. It involves a solenoid actuating a movable iron core and carrying at its lower end an insulated contact disk which in its upward travel engages stationary contacts, thereby operating the tripping circuit. The restraining and resetting force is furnished by gravity. Attached to the upper end of the core is an air bellows which is compressed during the upward travel of the core and which, through a suitable valve arrangement, retards the action of the relay in the inverse proportion to the current flowing in the solenoid.

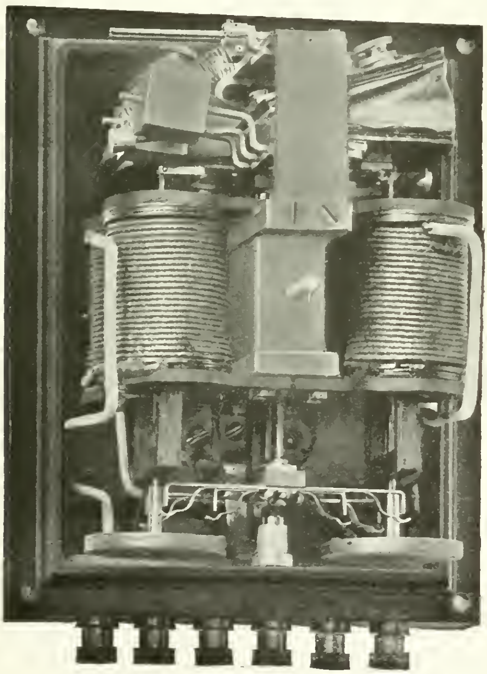


FIG. 23—POLYPHASE ALTERNATING-CURRENT RELAY—INVERSE TIME ELEMENT ACTION

Two of the above elements, as shown in Fig. 23, when enclosed in an iron case, constitute a complete relay. Two series transformers connected in "V" are required with each relay for the protection of three or four wire two-phase circuits and three series transformers connected in "Z" are required with each relay for the protection of three or four wire three-phase circuits as shown in Fig. 24. The range of the overload adjustment is four to eight amperes, being varied by the addition of weights to the contact ring. Normally the relay will operate at four amperes without weights. Four weights

for 5, 6, 7 and 8 amperes are added as necessary to give the corresponding overload values when placed over the contact ring.

The time element adjustment is effected by varying the distance by means of a key. To increase or decrease the time the contact distance is increased or decreased proportionately. The curves in Fig. 25 show the relation between the time required to trip and the amperes flowing in the relay for various overload settings and with contacts spaced one-half inch apart. Curve *A* represents the condition when the relay is adjusted for four amperes (all weights omitted).

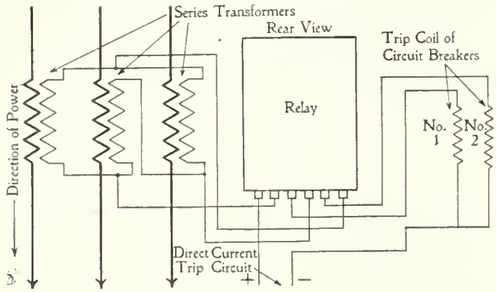


FIG. 24—CONNECTION DIAGRAM

Three-phase overload relay—inverse time element action, with two trip circuits, transformers connected in "Z."

Curve *B* represents the condition when adjusted for five amperes (weight five added). Curve *C* represents the condition when adjusted for six amperes (weight six added). Curve *D* represents the condition when adjusted for seven amperes (weight seven added). Curve *E* represents the condition when adjusted for eight amperes (weight eight added).

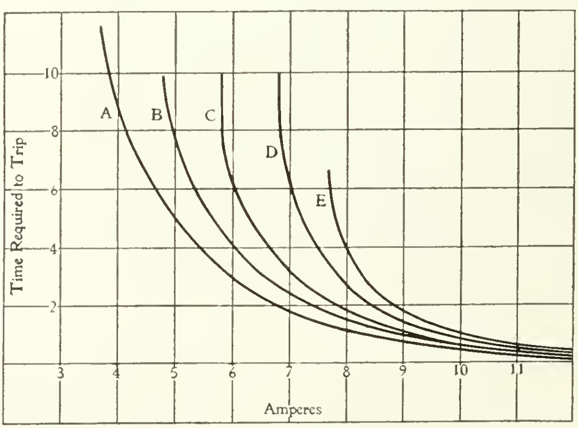


FIG. 25—CURVES SHOWING OPERATION OF OVERLOAD RELAY WITH INVERSE TIME ELEMENT ACTION

Thus if set for eight ampere tripping, for example, an overload of eight amperes will cause the relay to operate in four seconds (curve *E*), and an overload of 12 amperes will give operation in one-half second.

(To be continued.)

EXPERIENCE ON THE ROAD

A HIGH-TENSION RHEOSTAT

N. C. OLIN

SOMETIMES a road man is hard driven to rig up quickly an efficient apparatus for loading a machine; particularly if it happens to be an alternating-current generator, and the load is required for testing purposes only. This task is made doubly hard when there is any question of efficiency, as in many cases the guarantee is made upon a condition of unity power-factor, a condition which in practice is never attained without the aid of auxiliary apparatus.

The writer was sent to make just such a test. A record of the experience will possibly be of benefit to those who may find themselves in a similar position. He has not forgotten the feeling of depression as he, with one assistant, tried for hours to obtain a set of readings that were reasonably satisfactory. The ammeter and wattmeter readings were so irregular as to be of little use, the power-factor was variable, and this, with the presence of the owner, who was none too patient and constantly asking for results, certainly made things exasperating. The generator was one of three 300 kw, three-phase, 25 cycle, 6 600 volt machines, direct-connected to water-wheels, the three supplying power and light to a paper mill some ten miles away. Operating in this mill were several large induction motors, driving pulp machines, their loads and consequent power-factors being extremely variable.

Satisfied that no good results could be reached under such conditions, the writer determined to build a water rheostat. The details and dimensions of this rheostat may prove useful to someone meeting with a similar condition, and not knowing any more about water rheostats than did the writer.

Two frames were first constructed for the top and bottom, exactly alike and in the form of equilateral triangles. Rough pine two-by-fours were used for this purpose. Through each corner of these frames a hole somewhat over two inches in diameter was drilled, the distance between centers being two feet. Then the frames were slipped over three pieces of two-inch iron pipe, six feet long and securely pinned. Near the top frame each pipe was drilled and tapped for a machine screw to act as a binding post and from each binding post a rubber covered wire was carried. The bottom of the frame, which will now be called a rheostat, was then

heavily weighted and a tie was made at the top exactly in the center, so that an upright position was assured for the rheostat when in the water and, therefore, a balanced load between phases. The total weight of the rheostat thus equipped was about 200 lbs. A beam, on the end of which a pulley had been attached, was projected from a window and the rheostat was lowered into the tail race below by means of a rope through the pulley, as shown in Fig. 1.

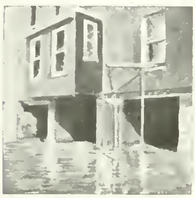


FIG. 1

Load regulation was attained by lowering and raising the rheostat; the load was steady and the balance between phases nearly exact. The writer was able to reach nearly 270 kw, 7 200 volts, with about two-thirds of the rheostat submerged and would have gone higher had it been possible to keep the water wheel up to speed with greater load.

A testing table was rigged up so that the current in any phase could be read on one standard ammeter and the voltage across any phase could be checked on a standard voltmeter. As no cut-outs or circuit breakers were easily available, a fuse block was rigged up by placing in each line two insulators about fourteen inches apart, breaking the wires at these insulators and turning them abruptly upwards. Around the skinned ends of each wire, and across the opening, between them, a one-ampere fuse wire was strung, giving enough turns to equal in capacity the ampere-load.

Having everything in place, the writer is free to confess that it was with a feeling of considerable uncertainty that he threw in the switch and, with one hand on the field switch, slowly built up the voltage with the field rheostat. But everything held and it was soon apparent that the dimensions of the rheostat were right.

At quarter load a puzzling thing occurred. Although enough turns with the one-ampere fuse had been taken to give the carrying capacity at this load, the fuse would not hold. Not heeding the advice of the owner to "wrap the whole spool on there," it was found that by skinning the wire a little more so that the fuse wire could be wrapped directly onto the copper wire, the fuse would hold as calculated. Not so when the turns of the fuse wire were wrapped one upon the other. The reason is easily apparent.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

46—Transformer Loading-Back Test. What is the relation of currents in the opposition or loading-back method of testing transformers under load?

G. D. B.

In the opposition method the iron and copper losses are supplied from separate circuits. The current supplying iron loss lags behind the e. m. f., the exact angle depending on the relation between the true loss and exciting components and being nearly 90 degrees at high densities where the exciting component is relatively large. The circuit through which the copper loss is supplied contains only the impedances of the two transformers. In small transformers the phase difference between the current and the voltage caused by the impedance of the transformers is small; in large ones, when working at 60 cycles or more, it may be as great as the lag of the exciting current. If the exciting current flows through the two transformers in opposite directions, the load current flows through both in the same direction. The resultant current in the winding of each transformer carrying the exciting current is the vector sum of the two components. If both losses are supplied from the same phase of one machine the resultant currents may be very nearly the numerical sum and difference of the components, thus causing considerable difference in heating. Assuming, for example, a transformer having an exciting current of ten percent of full-load at a power-factor of 43.5 percent, let the total resistance of each transformer be 4.35 ohms and the total impedance be ten ohms. The power-factor of the loading current will therefore be 43.5 percent, the same as that of the exciting current. If, then, both transformers are supplied from the same phase of a generator, there will be a resultant current 90 percent of full-load current, in one transformer and 110 percent in the other. The resultant copper losses will be respectively 81 percent and 121 percent in the windings exciting the transformers. For this reason it is customary to use the two phases of a two-phase machine to supply the two losses. The two currents are thus kept approximately 90 degrees apart, thus approaching full-load conditions and making the heating effect approximately the same in both transformers under test.

E. C. S.

47—Direct-Current Transmission. Will you kindly inform me as to the present limitations of high tension, direct-current transmission? In the proceedings of the A. I. E. E. for June, '07, mention is made of a 60 000 volt line into Lyon, France, using Thury patents. Can you tell me what these cover? Have been unable to find any information on this subject and would appreciate it if you will give me a pointer.

D. C. P.

The Thury patents cover a direct-current constant-current system in which a number of constant-current commutator type generators are placed in series to develop the desired transmission voltage.

Instead of current varying with the load as in the constant potential alternating-current system, the voltage varies with the load, the current remaining constant.

To make use of the power at the distribution end a series of motors similar to the generators must be used and each one of these motors must drive an alternating or direct-current generator for the usual constant potential distribution.

As with the alternating-current constant potential system the practical limitation of voltage is somewhat uncertain but such limitation is probably above that of the alternating-current systems. The difficulties probably lie more in other directions, such as construction of the genera-

tors, the necessity of conversion of the power to a constant potential system before secondary distribution can be accomplished and the general objection to very high voltage machinery having moving parts which must carry current at such high potential.

In the Journal of the British Institution of Electrical Engineers for January, '07, appears a complete illustrated description of this system (Highfield, Journal of I. E. E., Volume XXXVIII., part 183). This paper is reprinted with full report of the discussion in London *Electrical Engineering* for March 14 and 21, 1907. It is also reprinted in the London *Electrician* for March 15, 1907. *The Electrical World* for October 20, 1906, contains a description of the Montiers-Lyons (France) transmission system, part of which is based on the Thury high tension, direct-current system. The system was described as one of the fifteen Thury systems in existence whose total capacity aggregated over 24 000 hp. This particular system operates over the longest distance, approximately 100 miles, and at the highest voltage that has thus far been attempted, namely, 57 000 volts.

R. P. J.

48—INSULATION TESTING. Why does potential break down insulation when applied and broken successively? For example, take ten brush holders which are insulated from the studs, connect the studs together and the holders together, then apply 6 000 volts between studs and holders, making and breaking the contact. The insulation on one of the studs is very apt to break down, why?

H. M. M.

When a high potential circuit is suddenly opened or closed a rise of potential occurs which may be considerably more than the normal voltage of the circuit. The maximum voltage obtained in this manner depends upon the instantaneous value of the voltage at the time when the circuit is opened or closed, and may amount to about double the normal voltage of the circuit. For this reason, the test voltage, when suddenly applied, usually gives a more severe condition than when it is gradually increased. While the insulation may withstand a sudden application of test voltage several times, if this is continued there will be a tendency for the insulation to weaken and ultimately break down. The same phenomenon may be observed in many other cases, when breakdown will occur in time at a lower stress than the material would withstand at first.

D. H.

49—A car is equipped with two 30-hp street-car motors. The armatures are each wound with 47 coils, each coil has two windings (right and left) and each winding has five turns. These coils were removed from the armatures and coils containing four turns of wire were placed in the core.

(a) What effect will this have on the armature?

(b) What effect will it have on the field coils? (The field coils were not changed at all.)

(c) What effect will it have on the working of the two motors in general?

(d) Should some of the layers of wire have been removed from the field coils to balance the four-turn armatures?

W. T. W.

(a) It was probably found that the same size of wire had to be used with four turns of wire in the armature slots as with five turns. The effect with the same current would be to increase the speed of the armature in the ratio of five to four and decrease the torque in the inverse ratio. Thus the output of the motor would remain practically the same. The reason for this increase in speed is that with four turns per slot, greater speed is required to give the same counter-e.m.f. as was obtained with the five turns per slot.

(b) There is no effect on the field coils if they are not changed.

(c) The motors would work together satisfactorily but at the higher speed noted above.

(d) There is no necessity of making a change in the field coils if the same size of wire is used in the armature as was employed for the five-turn winding. If it had been possible to use a larger size of wire it would have been advisable to increase

the size of the wire in the field coils and decrease the number of turns.

J. L. D.

50—FUSES—What over-load carrying capacity should a properly designed fuse have? What effect has a time element?

H. E. E.

The Underwriters' Rules specify as follows, as regards enclosed fuses: "Fuses must be so constructed that with the surrounding atmosphere at a temperature of 75 degrees F. they will carry indefinitely a current ten percent greater than that at which they are rated, and at a current 25 percent greater than the rating, they will open the circuit without reaching a temperature which will injure the fuse tube or terminals of the fuse block. With a current 50 percent greater than the rating and at a room temperature of 75 degrees F. the fuses, starting cold, must blow within the time specified below:

0— 30	amperes.........	30 seconds
31— 60	"	1 minute
61—100	"	2 minutes
101—200	"	4 "
201—400	"	8 "
401—600	"	10 "

The time element feature of fuses has been the principal reason, next to cheapness, for their continued use. Momentary overloads that would not damage the apparatus do not blow the fuse, whereas a circuit breaker would trip out and interrupt service. Also fuses open quickly on heavy, dangerous overloads and more and more slowly as their severity decreases. (Note also first paragraph of article on "Carbon-Break Circuit Breakers" in this issue of the JOURNAL.)

51—COMPOUNDING OF DIRECT-CURRENT MACHINES—Having had occasion recently to compare several direct-current machines of some of our leading manufactures, I noticed the fact that the compound-wound motors are all of the long compounding type. I would appreciate it very much if you would explain the "whys and wherefores" of this particular feature. I have not noticed this point brought out in any book, but feel that there must be some good reason.

F. O. S.

By making the connections of the shunt field as near the source of power as possible, the voltage on the field is slightly higher and more nearly constant, and consequently the voltage regulation of the generator or speed regulation of the motor is slightly better than if the shunt field were so connected as to be affected by the varying drop in the series field. The designing of machines is simplified if it is known that the drop in the series fields does not have to be considered when determining the size of wire and number of turns of the shunt field coils. This matter need not, however, be considered as a very serious one either in regard to operation or design.

52—Please suggest some formula for making an insulating compound for the refilling of controller cylinders.

J. L. C.

We suggest: Dextrine, 1 part by volume; plaster of paris, 2 parts by volume; mix with shellac to form a paste, bake immediately after filling. The exact material could probably be obtained from the manufacturers of the controller.

A. B. R.

53—Referring to the diagrams on page 490, Vol. I., of the JOURNAL:

(a) What cases call for the application of three-phase V and three-phase T connections of transformers?

(b) Is any two or three-phase connection reversible?

(c) Will three-phase V and T-connected transformers operate as well on balanced load as the usual star or delta connected transformers and what are their advantages?

(d) Is it possible to make these connections (approximately) on standard transformers?

L. W.

(a) The advantage of the V and T conections lies in the fact that two transformers are required instead of three, thus reducing the first cost and floor space. The chief commercial use of two transformers so connected is in starting alternating-current motors on reduced voltage. In such cases the load is nearly always balanced and fine performance is unnecessary, but low cost and compactness are important since the transformers are in use only a few minutes each day. The

V-connection is used in this service because the point to which both transformers are connected may be left intact and the reduced voltages obtained by bringing the other two leads to taps on each transformer at an equal number of turns from the common point, while with the T-connection the arrangement would be more complicated. Another important use of the V-connection lies in the fact that if one of a group of three transformers connected delta is disabled it may be cut out and the other two used without changing any connections. The two remaining transformers will, however, give only 57.6 percent ($1 \div \sqrt{3}$) of the output, of the three with the same heating. The T-connection is very seldom used.

(b) In any balanced polyphase system there is a constant and continuous flow of energy. Any polyphase system may be transformed into any other polyphase system without storing energy; that is, with static transformers. This being the case, it is indifferent whether the transformation is from three-phase to two-phase or vice versa, as any connection which will do one will do the other equally well.

(c) There is no case where the delta or Y connection of three transformers will not give a better performance than the V or T. The regulation is inherently poorer when only two transformers are used even on balanced load. Under ordinary service conditions the T-connection will maintain balanced phase relations fairly well, but in the V-connection a slight distortion will cause large unbalancing of the secondary voltages and primary currents.

(d) Any two transformers of like characteristics may be connected in V for the same ratio as they would give when operating single phase. Thus connected, they will give 86.6 percent of their rated output for normal heating. Two similar transformers may be used for T-connection also. If no taps are available so that it is necessary to use the whole winding on the transformer which has but 86.6 percent voltage impressed, the current must be increased 15 percent to get normal output. On balanced load the current in the other transformer is 15 percent greater than the load it is delivering, so that the copper loss for this system is 30 percent greater than for the same output when the two transformers are operating single phase. E. C. S.

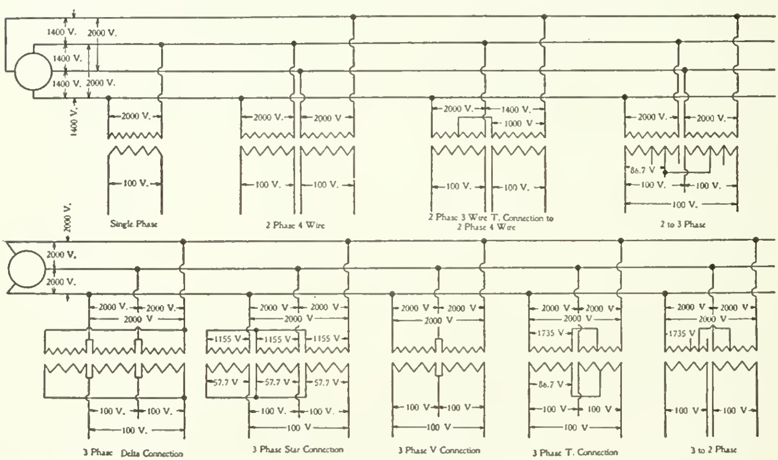


FIG. 53

Reproduced from the diagram on page 490, Vol. I.

THE
ELECTRIC JOURNAL

VOL. V. MAY, 1908 NO. 5

The Widening Sphere of the Engineer

The policy of the state of New York toward public utilities—which finds its latest expression in the recently appointed Public Service Commissions—was reviewed by Chairman Stevens, of the Second District, or "Up-State," Commission in his address at the Public Service Dinner of the American Institute of Electrical Engineers. He pointed out the various attitudes which the state had assumed toward such public enterprises, and remarked that the necessity for dealing with matters of this kind and the beginning of the formulation of a policy dates from about 1825 when the railroads were beginning to be of importance. Many developments have followed which are of vital public concern and toward which the state must establish a definite policy.

Transportation by rail, by water and by electric cars, lighting by gas and by electricity, the utilization of water-power and its transmission by electricity, the distribution of electric power, the telegraph and the telephone are all matters of vital public concern, whose proper direction, organization and control constitute our largest and most important problems, governmental, economic and financial. Mr. Stevens might well have added that while the railroads made a policy toward public utilities necessary, it was the Engineer who furnished the utility. And so with the many later developments which serve on a large scale the necessities and the convenience of the public, the underlying elements both in their inception, in their construction and in their operation depend upon the Engineer.

The dinner at which Mr. Stevens spoke is itself significant of a larger interest of engineers in their work. It is not usual for a professional engineering society to take up at its annual banquet so non-technical and serious a topic as Public Service. The public utility company—often regarded as a corrupt corporation privileged to prey upon the public—was treated in a broad gauge way as an instrument, not for private or corporate gain, but for rendering efficient service.

The April meeting of the Institute indicated again the widening

interest by a paper on "The Engineer's Activity in Public Affairs." The treatment is along broad and common sense lines. It is a simple, logical deduction that the engineer who conceives, designs, constructs and operates the physical plant by which the public may be efficiently served should be likewise active in administration and in shaping general policies. One gentleman—a lawyer—in discussing the paper took exception to the proposition that engineers should be appointed to places on the Public Service Commissions on the ground that too many would be required to cover the field; a gas engineer would be useful in connection with gas plants, but would be of little consequence in connection with railroads or water ways. Hence he concluded that business men or lawyers or public men, capable of dealing with things broadly, are more appropriate as members of commissions. But he failed to grasp the fundamental point that the need is not for engineering specialists but for engineering methods. The same ability to recognize and ascertain the underlying facts, the same necessity for logical reasoning from these facts to correct conclusions, the same requirement for useful, efficient and economical results which are essential in the engineering structure of a public utility are also essential in its administration. The red tape of legal methods, the devious ways of the politician, the modern methods of high finance must give way to the direct methods, the regard for facts and the securing of efficient results which characterize successful engineering. An engineering training should produce men who can extend engineering methods into these wider fields.

Some other recent events which show the extending field of the Engineer are the recent meetings of several of the Engineering Societies which have been devoted to a consideration of our natural resources; the memorializing of Congress by the American Society of Civil Engineers with reference to the preservation of our forests, which is the first occasion on which this Society has taken an action of this kind; the invitation of President Roosevelt to the Presidents of the National Engineering Societies to attend the conference of the Governors of the States with reference to the preservation of our natural resources. The larger position which engineering is taking in modern affairs was recognized and furthered by the gift of a home for the Engineering Societies by Mr. Carnegie.

The recognition of the larger life of the Engineer is also shown in technical education. There is an active agitation among the alert leaders in our Engineering Schools in which the general tendency is now toward a broader education and a training which will make

Engineers much more than mere technical experts. The address by President Humphreys, in this issue of the JOURNAL, voices this sentiment.

Engineering developments underlie the changes which have taken place in the past few decades in industry, manufacturing, transportation and public utilities. The changes which have occurred have necessitated radical and tremendous readjustments—industrial, social and economic. Sometimes these new relations have been assumed smoothly and sometimes they have resulted in a panic or a crisis. The difficulties of 1873 have been characterized as disturbances incidental to the adaptation to new economic conditions. Likewise, the panic of 1907 may be attributed to the ill-adaptation of financial and economic systems for coping with the larger scale of activity which has been brought about through the conduct of business and commerce on a new scale of largeness which in turn has been made possible by engineering developments; in other words, to a lack of engineering method and ability in handling the financial and economic administration of affairs, the engineering operation of which is successfully performed.

CHAS. F. SCOTT

Standardizing Power House Wiring

The theory of the main connections for polyphase systems, involving simply the alternators and motors with their translating and switching devices, is very familiar to the average engineer, and ordinarily he has no difficulty in connecting up this apparatus for service. It is a pretty safe statement to make, however, that there are few erecting engineers of any experience who will not readily recall some occasions when they have been obliged to retire to the solitude of their own rooms in order to work out some of the problems involving difficulty with meter or relay connections.

Sometimes the difficulty has manifested itself in some apparently simple combination of meters and transformers in a small plant. But it is generally the large three-phase generating station with a complete equipment of meters and protective relays which offers the most fruitful field for contemplation of this nature; especially if connections are made for a grounded neutral or a three-phase four-wire system.

The connections would not be so complex at times if it were not common practice to connect groups of switchboard apparatus on

the same sets of series and shunt transformers in order to avoid a multiplicity of transformers. In addition to this large stations are often laid out with all control and instrument wires in cables and run in conduits so that they are not so easily traced out as in small stations where short open wiring is involved. In some stations the practice of supplying each separate conductor with a braided covering having a distinct coloring to distinguish it from its neighbor has facilitated the mechanical process of tracing out the leads.

A few plants have been installed where the entire system of instrument and relay wiring has been placed in iron conduits and as many extra wires eliminated as possible, on account of the long runs and the number of conduits required. Where this is to be accomplished by using the common grounded connection from the series transformers as a return circuit, and at the same time so connecting the apparatus that the resultant current in this wire may be neutralized, to prevent excessive drops due to the effects of the iron piping, an interesting complication of currents will sometimes be met with which will tax the ingenuity of a veritable wizard.

As the reliability and economy of the entire electric plant depends upon the successful operation of the meters and relays, too much cannot be said regarding the importance of a good system which will enable the engineer to determine the accuracy or inaccuracy of a diagram or set of connections. The article in this issue of the JOURNAL, on "Meter and Relay Connections," by Mr. Harold W. Brown, presents a convenient and reliable system for such determinations, which is based upon long experience. It should be of much interest to all engineers who are connected with power station work.

BERTRAND P. ROWE

BUSINESS ENGINEERING*

ALEXANDER C. HUMPHREYS

President, Stevens Institute of Technology

WE frequently hear the statement made that it is not the high-scholarship man who best succeeds in the world of work; and frequently we find men, who should know better, going so far as to claim that high scholarship is a disadvantage. I believe the explanation of this paradox is found in the fact that educators, and sometimes even so-called practical business men, fail to appreciate that, to attain the largest measure of success, the equipment must consist of a combination of that which can be and is acquired within the college walls and that which can only be acquired outside the college walls. It is not a question of theory *or* practice; it is theory *and* practice. If the theory is complete, there can be no disagreement between theory and practice; but to be complete the theory must take account of all limiting conditions, general and special, including return on capital investment and the human agencies to be employed.

Supposing a student graduates with a grade of ninety, but, through one cause or another, at the end of five years after graduation, his grade in the school of practice and experience is, say, only thirty; his combined average then is only sixty and, as a doer, his ability is mediocre or worse. Supposing, on the other hand, a man graduates with the lowest possible passing-mark of sixty; that, at the end of five years, he has attained a grade in the school of practice and experience of ninety; his combined average shows a grade of seventy-five. But, as a doer, the comparison is still more favorable to him than is indicated by the difference between 60 and 75, for he is better able to put into effect the smaller amount of theory which he has acquired in the college. But now suppose we have a man who has graduated with the average grade of ninety; and at the end of five years he has acquired in the outside school a grade of ninety; his combined average would be ninety. And, here,

*From an address delivered at the annual dinner of the alumni of Stevens Institute of Technology at the Hotel Astor, New York City. In the first part of the address Dr. Humphreys discusses and takes issue with the recent criticism by Mr. R. T. Crane, of Chicago, upon present methods of technical education. This is followed by the general consideration of the relations of the engineer-student to practical work and the relations between engineering and business, which in slightly condensed form is here reproduced.

we have a man of high scholarship who will be able to demonstrate by results obtained that scholarship does count.

If we can do no more within the college walls towards the correction of this weakness which too often is found in the make-up of technological graduates, we should, at least, do all in our power to convince them before the day of graduation that this additional training in the school of practice and experience is a prerequisite to real success; and here I mean far more than mere money-making. But more than this can be done within the college walls, notwithstanding the fact that the college training must be supplemented as shown. We could and should give these students a preliminary training that will prepare them to advance quickly and surely in the lines of practice and administration just as we are preparing them, through the technological training, to advance quickly and surely along lines having to do more particularly with the theories of engineering science. Primarily, it should be impressed upon the engineer-student all through his college course that the purpose is not to make him a man of science as much as a man qualified to apply science practically. He must be taught that it is necessary to thoroughly understand and to be able to reason accurately from his understanding, rather than to memorize a mass of data. He needs to be trained to analyze data correctly, and to store data in his head.

It is coming to be recognized outside the college walls—and it must be recognized within the college walls—that the engineer to be really successful and, especially, as an industrial manager (which is coming more and more to be his vocation), needs to be a man of affairs as well as a technologist. He must have a knowledge of men as well as of engineering science. His engineering theories must be qualified, and in no small degree, by commercial sense. He must have a good working command at least of his mother tongue.

There is just now apparent a considerable movement in favor of broadening the college education of the engineer. It is coming to be recognized that the courses, as laid out in America some years ago, were too narrowly specialized. But let us not, in correcting this fault, according to the American tendency so often exemplified, for instance, in our amateur efforts at political reform, rush from one extreme to the other. It is not a question between intensive study *or* broad study, but there is required intensive specialized study *and* broad study. In our desire to correct specialized narrowness, we must not run into superficial breadth; bad as it is, better by far the first than the last for general efficiency.

With a good fundamental training, better for the majority that they should go out into the world and work and so get their post-graduate training. Professional educators are too apt to think that the only schools are those in which they teach; they fail to appreciate as they should the educational value of the school outside the college walls in which their students are to continue as learners as long as they remain in practice. Even practicing engineers too often fall into this error and so we find them demanding of their young assistants a maturity of judgment which it has taken them ten, twenty or thirty years to acquire in this school of practice and experience, and failing to find this maturity, the blame is laid upon the engineering school.

Unquestionably, the student would get greater value from his college studies if he first was forced to face the problems of life. On the other hand, the same man should at once get more experience from his work in the shop or field if he first had the college training. But the question thus raised is not of quite so much importance as some believe, because many engineer-students have had practical experience before coming to the school of engineering and many more take outside employment during the long summer vacations.

In any case, the man who has taken a full course in a school of engineering of high grade, even if graduated only at sixty percent is equipped to acquire more and acquire more rapidly from his work in the school practice and experience than the man who has not had the benefit of this preliminary systematic training in the science of engineering.

But I come now to certain views which I believe to be of vital importance in connection with the efforts to correct the weaknesses evidenced in our system of engineering education. Not a few educators and more engineers hold these views and some efforts generally weak and halting, have been made to carry them into effect. As far as I know, at Stevens Institute we have gone farther than at any other school of engineering. I refer to the work that is, in part, covered in our department of Business Engineering.

When I became president, I took personal charge of and endeavored to develop this department, but, with the hours so far available, the result has been by no means satisfactory to me.

Under the present arrangement, the most I can attempt is to show the students in a broad way that economic and commercial conditions must limit and control engineering designs and enterprises and give the students a fairly sound knowledge of the

principles of accounting, depreciation and accounting as applied to depreciation. I also give them some instruction in the preparation of estimates and specifications, the analysis of data, the rudiments of banking; and a special lecturer gives about four lectures on contract law.

In my work in Business Engineering I have been feeling my way; but now, after five years' experience in this department and as President, I am prepared to state unhesitatingly that this course can be made of great value and therefore should be further developed. The course should be enlarged to include practical economics; more on banking, accounting, factory management, office administration, and professional and business ethics; and some general scheme to cover, as far as possible, business and commercial methods in general.

Incidentally, this course could be made to serve the purpose of showing the embryo engineer that there is more in life than engineering and money-getting and that, in developing to the utmost his powers for efficient service, the things outside the field of engineering must not be neglected. Especially could this purpose be served by including in this course lectures to be delivered by men selected for their inspiring personality, who have made their mark *apart from the field of engineering,* and who would particularly desire to impress upon the students their obligations as servants of the community, state and nation.

Last year in the United States there were graduated from the more important colleges and universities alone about three thousand engineering students. This is a large increase over twenty years ago; but even at the yearly rate thus decreasing back through the twenty years, let us suppose that all the engineer-students graduated from these institutions during this period had been required to pass at least as high as sixty percent in such a department of practical economics and administration; can we not easily conceive that these men would have exerted their influence most favorably in the fields of commerce, industry and transportation and, especially, at the time of such a financial crisis as that through which we have just passed? Instead of now being able to depend upon the technologically educated men as a class for sane actions and sane opinions for the guidance of others who have a right to look to them for guidance in industrial affairs, do we not too often find them exhibiting their ignorance and inexperience through destructive criticism? It is natural that the uninformed public should take it for granted

that the educated engineer is competent to guide in all parts of the industrial field. The educated engineer should not encourage this error, but while modestly withholding his opinions on questions in which his practical experience has not qualified him to speak with authority, he should speak and act fearlessly on questions wherein he is qualified by reason of special training and practical experience.

Let the industries of the United States pass into the hands of men educated thoroughly and broadly, theoretically and practically, technologically and commercially, and certainly we should be in less danger from the promoter and speculator on one hand and the amateur reformer, doctrinaire and man-on-the-barrel on the other. Then we should be in less danger of panics. What we want in these men, many of whom in the future are to be industrial leaders, is a highly cultivated common-sense and sense of justice. If it is advisable that in the school of engineering these men should be prepared to apply quickly and accurately the theories developed through the study of mathematics and the natural sciences, should they not be instructed as to the commercial and ethical conditions which are to limit or enlarge these theories? Certainly no distinction should here be made against any of the subjects which go to make the engineer, in the best sense, practical, for, by definition, he is not an engineer if not practical.

Engineering education has been criticized by practical men of affairs, largely, because of the errors made and inadequate results obtained in the absence of such departments in our schools of engineering. Then is there not here presented an opportunity for these men to indulge in constructive rather than destructive criticism? The men of the United States to-day who have made their fortunes in the fields of commerce, industry and transportation, whether they recognize it or not, are largely indebted to engineering science and engineering education, in spite of its minor faults. Let them then show their appreciation by a broad-minded acknowledgment of these claims and by co-operating with us to remove these faults, that so we may be able to give to others still more than our alma mater has given to us.

SOME POINTS IN THE DESIGN OF LARGE GAS ENGINES

AS EXEMPLIFIED IN THE WESTINGHOUSE HORIZONTAL TYPE

THE modern large gas engine should not be considered as a new product, but an evolution—the result of about ten years' active development of various sizes and types. In present designs may be found numerous evidences of earlier development in both land and marine steam engineering, and in gas engines of various types. In fact the large gas engine of to-day more nearly resembles the heavy duty steam engine than its predecessors in the gas power field, and the experience of its builders, in steam work, has naturally become a corporate part of the present design.

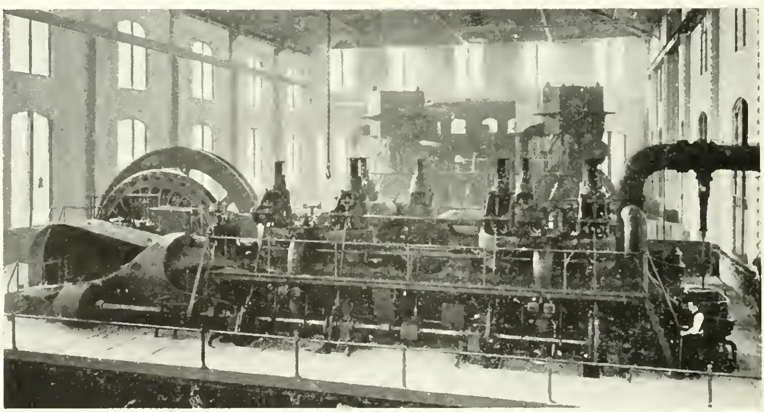


FIG. 1—2 000 KW HORIZONTAL GAS ENGINE AND GENERATOR AT THE EDGAR THOMPSON WORKS OF THE CARNEGIE STEEL COMPANY

The steam engine-generator set in the background, has the same rating as the gas engine set.

As in the case of any manufactured product, the specific features of the design are largely dictated by commercial requirements. Thus, the American design of large gas engine is characterized by the utmost simplicity possible, as is evidenced in early forms of the single-acting type and later, when larger sizes were in demand, in the double-acting type. The immense growth in the gas engine business, in the case of one builder alone, is evidenced by a

total of 162 000 brake horse-power in engines operating or on order, representing the equipment of 648 plants for every service to which steam engines have been applied, including 25, 40 and 60-cycle parallel operation. These engines are operating on every kind of fuel gas available—natural, illuminating, coke oven, by-product oil distillate, blast furnace and producer gas. Although these gases vary from 90 to 2 000 B.t.u. per cu. ft., they yield very nearly the same engine efficiency and practically the same design is employed, except that a somewhat larger cylinder is used for the leaner gases.

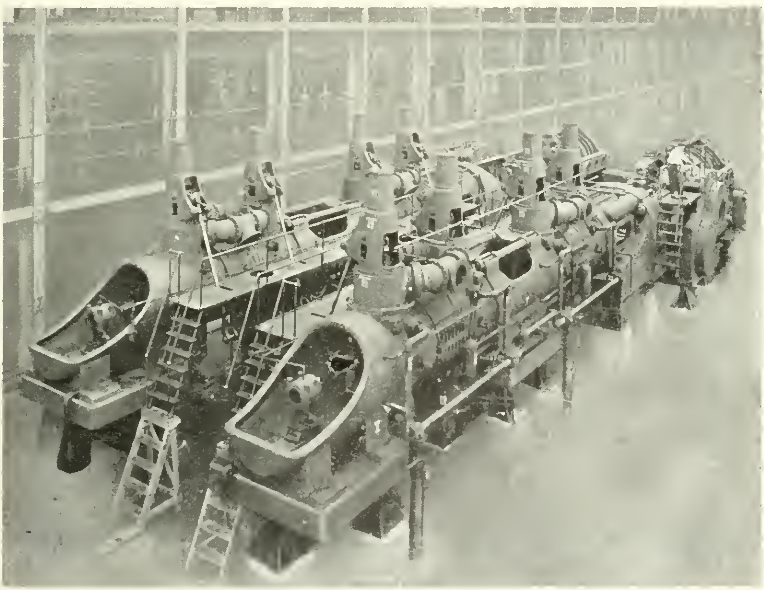


FIG. 2—3 000 HORSE-POWER BLAST FURNACE GAS BLOWING ENGINE SET ON ERECTING FLOOR

Speed 75 r.p.m., cylinders 42 by 54 inches.

Producer-gas development has been particularly rapid and it may be said that the future of the gas engine practically rests in this field. In March, 1908, there were in operation, mostly in America, 122 producer plants up to 3 000 brake hp capacity, and aggregating 68 000 brake hp. In these plants, wood, coke, anthracite and bituminous coals of various grades, and even low grade western lignites are being used successfully. Blast furnace gas, the ideal producer gas, represents the largest single industry, especially in the demand for large units, and the design discussed below largely

pertains to the power equipment for the steel mills at Bessemer, Pa., and Gary, Indiana.

General—Two fundamental differences exist between the gas and the steam cycle. First, the gas engine performs within its cylinders the combined work of boiler, furnace and the steam engine; i. e., without an intervening medium of energy transmission. This obviates a large proportion of the losses to which the steam cycle is subject, but also incurs the mechanical disadvantage of extreme temperatures—much higher than in superheated steam plants. This is, however, circumvented by water cooling of all parts subjected to the heat, at the same time extending the working thermal

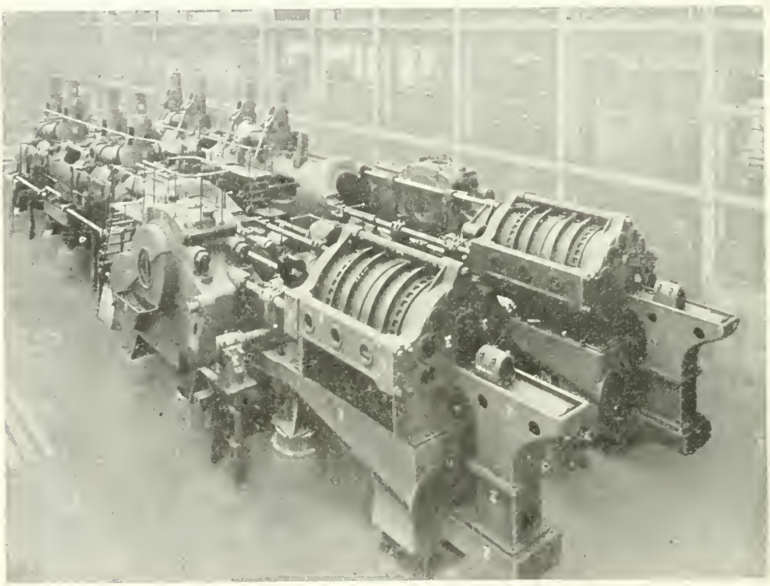


FIG. 3—ANOTHER VIEW OF ENGINE IN FIG. 2, SHOWING BLOWING TUBS IN FOREGROUND

range entirely beyond the range approachable in the steam cycle. Hence, the high heat efficiency shown by gas engines, about 10 000 B.t.u. per brake hp-hr. The second difference is in the pressures encountered. Whereas maximum steam pressures are fixed by the boiler pressure, gas pressures are variable and may run as high as 500 pounds per sq. in. Hence gas engines require considerably more metal throughout to withstand safely the pressures likely to be encountered, and it is largely on this account that the horizontal

type has become standard. With the tandem arrangement of cylinders for electric driving the length of the engine becomes somewhat excessive for a vertical design. The horizontal arrangement gives the necessary rigidity and also provides the much desired accessibility to all working parts from the floor level.

Another fundamental difference between steam and gas is that the latter must supply itself with fuel. This necessitates either an additional stroke as in the four-cycle engine, or an auxiliary pumping outfit, as in the two-cycle engine. The former is, of course, the simpler method, and with tandem cylinders, yields one power impulse at each stroke, as in a double-acting tandem steam engine. In the twin tandem arrangement, as shown in the illustrations of the Bessemer and Gary engines, Figs. 1, 2 and 3, with cranks 90 degrees apart, the frequency of power impulses is doubled, and the crank effort correspondingly improved.

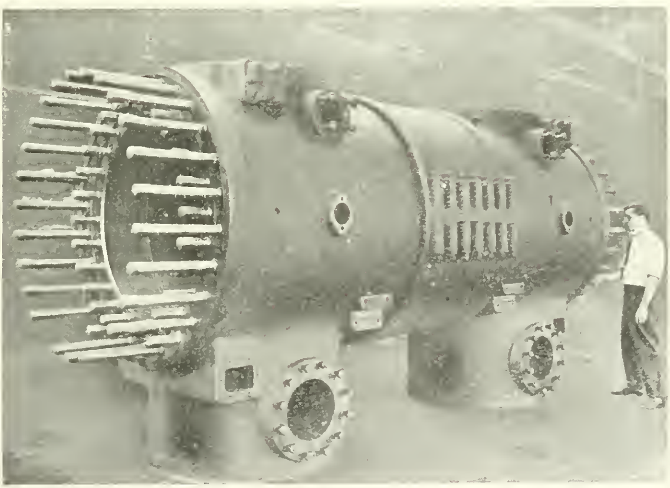


FIG. 4—CYLINDER FOR 3 000 HORSE-POWER BLAST FURNACE GAS ENGINE IN PROCESS OF CONSTRUCTION

Arrangement—Essentially the design illustrated comprises a horizontal cylindrical structure anchored forward, but otherwise free to expand and contract along the axis of the engine. The cylinders, in a structural sense, are simple beams supported at the two ends and affected only by a dead load, their own weight. The pistons are supported entirely from front, center and rear crossheads and float free from the cylinder walls. The cylinders are

accessible, not only as regards the cleaning of the water jackets, but also the inspection of the interior by the removal of either exhaust or inlet valves. This is one of the principal reasons for the vertical location of the valves, as shown in Fig. 4, and in section, in Figs. 5 and 6. The piston rods are made in two parts and may be separated at the center and each half removed at the front and rear. This avoids extensive dismantling of the engine, and the necessity of a large building clearance to remove a one-piece rod.

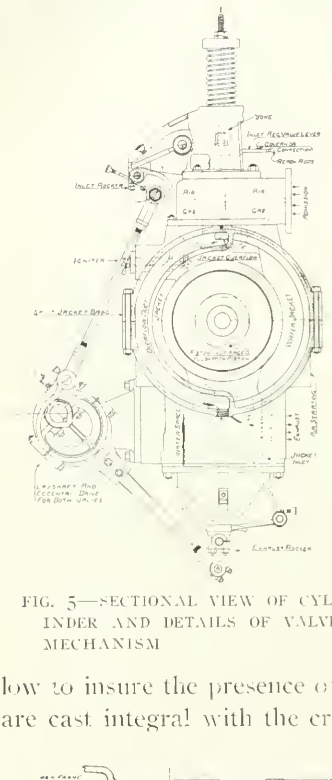


FIG. 5—SECTIONAL VIEW OF CYLINDER AND DETAILS OF VALVE MECHANISM

Shaft and Bearings—With the side crank construction now standard, the number of bearings to be kept in alignment is reduced to a minimum. In addition, the main bearings are provided with spherical seats so as to be self-centering and by relieving them of the weight of the shaft, a bearing shell may be revolved out of its seat without further dismantling. Shafts are of forged steel, bored hollow to insure the presence of homogeneous metal. The crank pins are cast integral with the crank dises, with the pin at the bottom of the mold, for the same purpose. Owing to the short stroke, it would have been impossible to employ pressed pins.

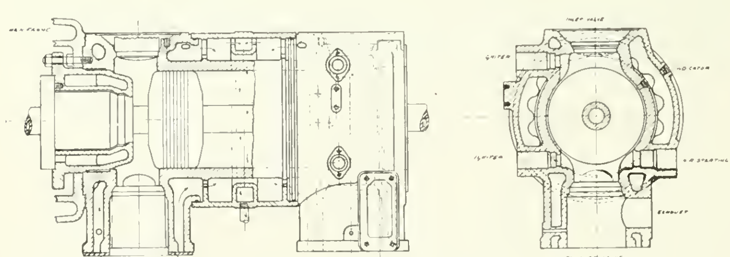


FIG. 6—SECTIONAL VIEWS OF CYLINDER SHOWING INLET AND OUTLET PORTS

Regulation—One of the most interesting features of these engines is the construction of the inlet valves, each of which com-

bines in a single mechanism the functions of inlet, governing and mixing valve. The advantages of this arrangement are apparent. Mixing the air and gas in the required proportions only at the point where used and in exactly the quantity required, gives the governor the most complete control over the admission of gaseous energy to the cylinders. Further, the constant movement of the various parts prevents the possibility of the governor valve sticking. Each mixing valve is connected to the governor (Fig. 7) by reach rods. Throttling of the mixture is accomplished by varying the area of the gas and air ports in the governor valve. Since, however, the areas of these ports always bear a constant ratio to each other, the mixture remains con-

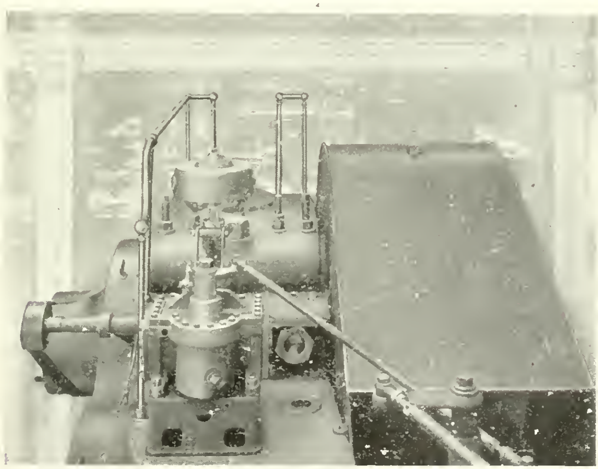


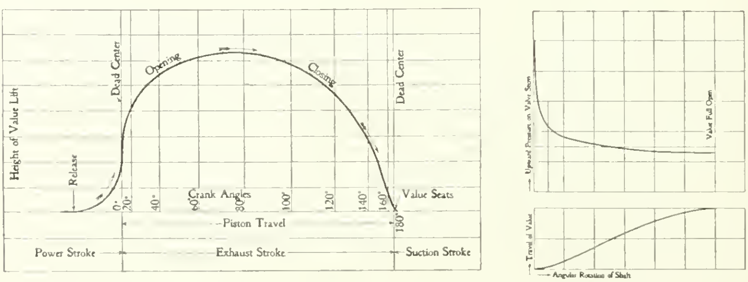
FIG. 7—DETAIL VIEW OF GOVERNOR MECHANISM

stant though the amount of mixture admitted to the cylinders varies. Hence, since the mixture remains constant, and the induction and exhaust stroke are separated, uncertainty of combustion is eliminated, and the highest efficiency of combustion may, therefore, be obtained at all loads.

In addition to the governor valve, butterfly regulating valves, which are moveable by hand to control the proportion of air to gas, are also fitted in the gas and air inlet ports.

The exhaust valves, only, require cooling and are, therefore, made hollow. A tube extending upward through the valve stem to the top of the valve serves as an outlet for cooling water and keeps the valve full.

Valve Arrangement—The valves are located diametrically opposite at the cylinder ends and hence the maximum distance between inlet and exhaust valves is obtained. This results in a minimum dilution of the incoming gases with the products of combustion, thereby increasing the rate of combustion and giving a higher mean effective pressure. Owing to the fact that the incoming gases do not come in contact with the hot exhaust parts and that all foreign matter tends to discharge downward with the exhaust, the principal source of pre-ignition is eliminated. The compression spaces are so formed that varying volumes needed, to give the compression required by different gases, can be obtained without changing the design of the cylinders, pistons or positions of the valves, this being accomplished simply by changing the bulk of the cylinder head protruding into the compression spaces.



Velocity Curve for Exhaust Valve based on Piston Travel

FIG. 8—DIAGRAMS SHOWING VALVE CHARACTERISTICS

Valve Drive—One distinctive feature of the valve mechanism is the use of a single eccentric for operating both the inlet and exhaust valves, through a rolling cam valve motion, which permits the rapid opening and closing of the valves, without hammering the valve seats. Thus the stresses imposed upon the lay shaft and valve mechanism through the use of the roller cam motion are very light, owing to the great leverage exerted by the cam at the beginning of the stroke. A diagram, taken from this valve mechanism while the engine was in motion, showing the characteristics obtained and the wide average opening, is given in Fig. 8. Wear on the roller cam surfaces is negligible because of the large bearing surfaces and adequate lubrication, and there is nothing which can possibly change the time of valve opening.

Governing—Speed regulation is accomplished by means of an oil relay system controlled by a centrifugal governor of either the

Jahns or similar type, driven directly from the main shaft. The sole function of the governor is to move a small pilot valve for controlling the oil to either end of the cylinder of a relay. It is, therefore, unaffected by friction in the valve mechanism or the force required to operate it. Reach rods from the oil relay pistons move the governor valves. The governor is fitted with a dash pot to prevent hunting and is capable of maintaining the speed of the engine within 2.5 percent variation from no-load to full-load.

Safety-stops—In addition to the governor, each engine is provided with a safety stop which opens the igniter circuit in case of over speeding, thus cutting off the power from the engine. A second stop is provided which opens the igniter circuit in case of failure of the cooling water supply. The first of these, as shown in

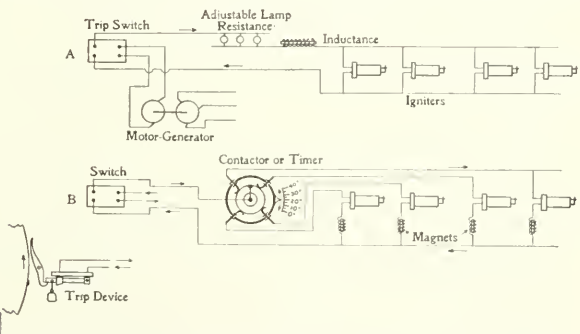


FIG. 9—DIAGRAM OF CONNECTIONS FOR ELECTRIC IGNITERS, ALSO AUTOMATIC OVER-SPEED TRIP

A—FOR MECHANICAL IGNITERS. B—FOR MAGNETIC IGNITERS

Fig. 9, consists of a spring-balanced pin in the fly-wheel rim which is forced outward by centrifugal action in case of over-speeding.

Ignition—The success of gas engine operation rests to a considerable degree in the igniter, which fact has influenced designers to use more than one igniter per cylinder. To accomplish this, the electrical system is evidently much better adapted than the familiar mechanical system of knock-off cams inasmuch as any number of circuits can be run to any desirable ignition point in the cylinder. This has led to the development of the electro-magnetic system illustrated in Fig. 9. In some respects the jump spark or high tension system, as widely employed on automobile and marine engines, is ideal, yet it fails on the high compressions necessary for lean gas due to the high resistance of the compressed atmosphere. Fig. 10 clearly illustrates the advantages of multiple ignition, both in the matter of more effective combustion and in increased mean effective

pressure, in this case nearly four percent. With larger engines, having three igniters spaced at equal distances around the cylinder, even better results should be secured.

With the magnetic igniter, two features stand out prominently: 1st, operating magnets and sparking points are in series, hence are obliged to work together. An open circuit thus means no motion; 2nd, the magnets furnish the required self-inductance to operate as the ordinary spark coil. Hence the entire ignition apparatus is largely self-contained.

Any number of magnetic igniters may be operated from a single contactor or timer, as shown diagrammatically and in detail in Fig. 9, and the much-needed method of changing the ignition according to the load is very simply accomplished by rotating the timer casing. Any igniter may be removed while the engine is in operation by closing the corresponding inlet and blocking open the exhaust valves, thus relieving the compression in that end of the cylinder.

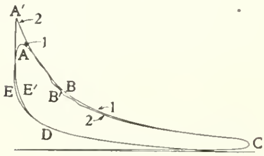


FIG. 10—INDICATOR CARDS TAKEN WITH ONE AND TWO IGNITERS IN OPERATION*

Lubrication—One of the most important elements in the successful operation of large gas engines, is the thorough lubrication of the cylinders, pistons, rods and exhaust valve stems. This important function is performed in a positive, economical and reliable manner by a system of timed forced sight-feed lubricators. Oil to the cylinders is supplied at four points in each cylinder during the suction stroke only, thus giving two cool working strokes, during which the oil is evenly distributed over the entire surface of the cylinder, in the spaces formed between the piston rings, piston and cylinder walls. The timing of the forced lubricators can be adjusted by shifting the pump eccentrics on the lay shaft shown in Fig. 11. Lubricating oil for the bearings is supplied from a central gravity system and sight feed lubricators. The entire oil supply to the engine is controlled by a single valve so that the supply can be shut off without disturbing the individual lubricator adjustments.

Cooling—Particular attention has been given to reducing the quantity of cooling water required for the engine. For this reason

*Number of Igniters	ONE	TWO	—INCREASE—	
	Lbs.	Lbs.	Lbs.	Pct.
Maximum pressure	272	335	63	23.2
Release pressure	30	30	0	0
Mean effective pressure	66.8	69.4	2.6	3.9

a series system has been employed to some extent. Individual circuits, each provided with an open discharge, make it possible to determine quite closely the temperature of each working part. As pistons and cylinder heads have about the same exposed surface, these parts are connected in series so as to secure a fairly uniform average temperature. The jacket spaces in the cylinders are purposely of ample dimensions to afford opportunity for occasional cleaning out of the sediment. Water enters the piston through telescopic connections located at the center crosshead and discharges at the front and rear into chambers cored out of the front and rear housings. The velocity of the water through rods and other restricted areas is high enough to prevent the deposit of sediment.

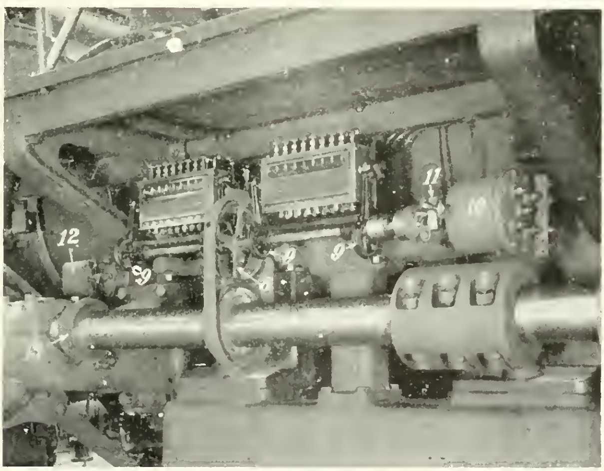


FIG. 11—DETAIL VIEW SHOWING LUBRICATORS AND CONTACT MAKER

Starting—As in smaller sizes, the horizontal engines are started automatically by compressed air through individual cams and poppet valves located along the lay shaft opposite each combustion chamber. With the igniters turned on, the engine starts itself after opening the compressed air, gas and air valves. As each cylinder picks up its ignition (after one or two revolutions), the compressed air supply is cut off automatically by means of a check valve, which is held closed by the combustion pressure. How effective this system is in practice, is best illustrated by the results regularly obtained at the Philadelphia high-pressure pumping station, where pressure is on the mains in less than one minute from the time of signal.

METER AND RELAY CONNECTIONS

STANDARD CONNECTIONS

HAROLD W. BROWN

THE purpose of this article is to present a few principles to be observed in making connections to switchboard meters and relays and to apply these principles to questionable cases that may arise. The conventions here used are those that apply particularly to Westinghouse apparatus, but the principles are general.* In all diagrams here shown, meters and relays are represented as seen from the rear, because connections are brought in from the rear of the switchboard.

ASSUMPTIONS REGARDING POSITIVE DIRECTION OF CURRENT

In alternating-current circuits the current flows in one direction during a part of each cycle, and is reversed during the rest of the cycle; similarly, the e.m.f. is in one direction during the first part, and is reversed during the rest of the cycle. Since both current and e.m.f. are reversed, the direction of mechanical reaction between the current coil of a meter or relay and the e.m.f. coil is the same in the second half as in the first half of the cycle. Either direction of flow of current may be arbitrarily called positive, provided a consistent assumption is made regarding the positive e.m.f.

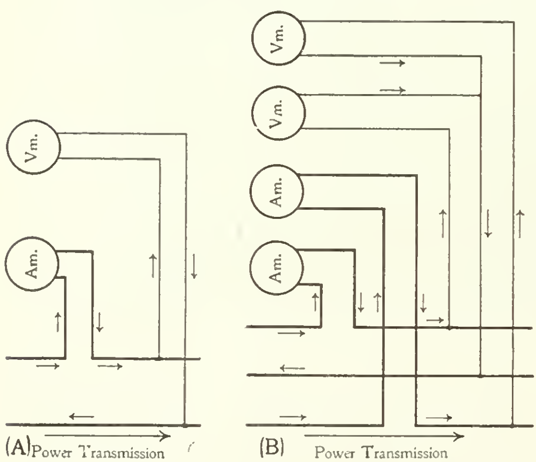


FIG. 1

If one of the conductors has in its circuit a series transformer

*For a fuller discussion of conventions, see an article by Mr. M. C. Rypinski in the *Journal* for February, 1907.

or any series instrument, whereas the other has none, it is convenient to assume that *the conductor having transformers or instruments is positive,* and that *the direction of current in that conductor is the same as the direction of power transmission.* In a three-phase system, if two of the three conductors have series transformers or series instruments and the third has none it may be considered, as before, *that the two with transformers or instruments are positive,* and that *the other is negative;* and that *the direction of current in the two positive conductors is the same as the direction of power transmission.* If a shunt transformer or any voltage circuit is connected from a line assumed as positive to one assumed as negative, the direction of current is from positive to negative.

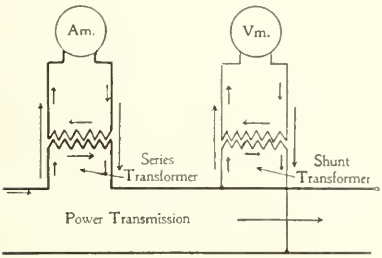


FIG. 2—DIAGRAM OF SHUNT AND SERIES TRANSFORMERS, SHOWING RELATIVE DIRECTIONS OF PRIMARY AND SECONDARY CURRENTS

In Fig. 1 (*A*) is shown an example of a two-wire circuit, in which the right hand line is considered positive. In Fig. 1 (*B*) a three-wire circuit is shown in which the outside lines are considered positive, and the middle line negative.

TRANSFORMERS

From the theory of the transformer, with primary current flowing in one direction around the core the secondary current flows in the opposite direction. This is of course true with reference to both shunt and series transformers and may be represented diagramatically as in Fig. 2. At any instant, if the primary current is flowing to the right through the transformer, the secondary, being opposed to it, is represented as flowing to the left as indicated by small arrows.

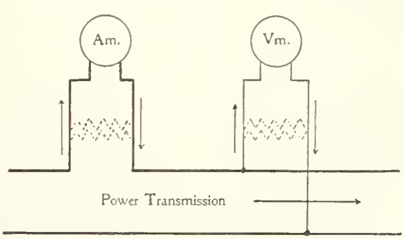


FIG. 3—IMAGINARY DIAGRAM ILLUSTRATING DIRECTION OF CURRENTS

Considering the direction of the primary and secondary currents outside the transformer only, *i. e.,* paying no attention to those inside, it will be observed that on the left, both primary and secondary

currents are upward, and on the right they are both downward, as indicated by the large arrows. In other words, in determining the direction of a secondary current, it may be imagined that, as in Fig. 3, the primary current jumps across from the left hand primary to the left hand secondary terminal and continues its flow through the external secondary circuit and back to the right hand primary terminal as indicated by the large arrows. This conception simplifies the checking of complicated diagrams. In practice it is customary to bring out the transformer leads in line with this assumption.†

RELATION OF CURRENTS IN CURRENT AND E.M.F. COILS

In wattmeters, power-factor meters and reverse current relays, it is necessary that the directions of currents in current circuits have the right relation to the currents in e.m.f. circuits.

Wattmeters—The single-phase wattmeter has one e.m.f. circuit and one current circuit. The polyphase wattmeter has the windings of two single-phase wattmeters, which deflect a single pointer. The power indicated by a polyphase meter is the same as would be indicated by the sum of the readings of two single-phase wattmeters similarly connected.

The polyphase wattmeter is so constructed that the left hand current circuit reacts with the left hand e.m.f. circuit and the right hand current circuit with the right hand e.m.f. circuit. That is, as shown in Fig. 4, e.m.f. circuit *a-b* reacts with current circuit *c-d*, and *e-f* reacts with *g-h*. Leads to e.m.f. circuits are brought out to binding posts in the upper part of the meter, and those to current circuits in the lower part. If the current in the left hand current circuit is in the same direction between binding posts as is the current in the left hand e.m.f. circuit, that is, if both flow up or both down, the meter indicates positive power; but if the current in the current circuit is opposed to that in the e.m.f. circuit, it measures negative power. In other words, referring again to Fig. 4, positive power is indicated if the direction of the flow is from *a* to *b* and from *c* to *d*, or if it is from *b* to *a* and from *d* to *c*, but if the flow is from *b* to *a* and *c* to *d*, negative power is indicated. Similarly on the right hand side, if the current of the current circuit is in the same direction as is that

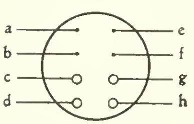
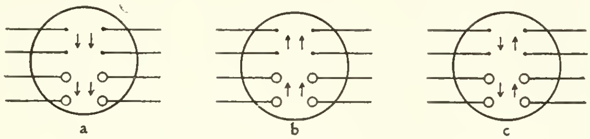


FIG. 4

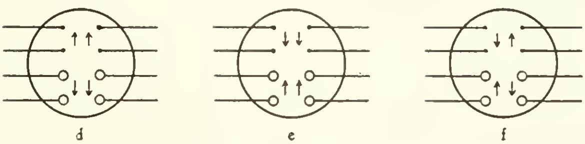
*Of course, when there is actually a cross connection required between primary and secondary to complete a circuit, the case must have special attention, but this seldom occurs.

of the e.m.f. circuit, the meter indicates positive power, but if the current is opposed to the e.m.f., the meter indicates negative power.

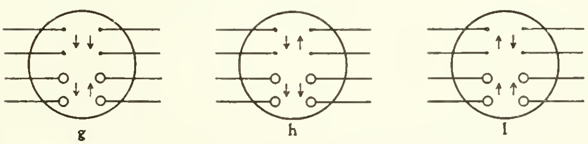
In Fig. 5 several combinations of currents in the various meter circuits are shown. In *a, b, c,* positive power would be indicated; in *d, e, f,* negative power; in *g, h, i,* there would be a positive deflection



Positive power (right).



Negative power (wrong).



Positive and negative power (wrong).

FIG. 5—POLYPHASE WATTMETER CONNECTIONS

due to the action on the left hand side and a negative deflection due to the action on the right hand side. The resultant deflection would be due to the difference between the power in the two sides.

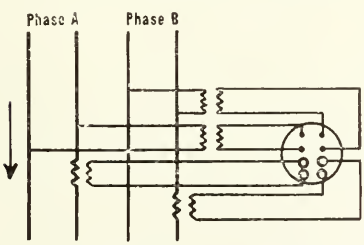


FIG. 6—POLYPHASE WATTMETER IN TWO-PHASE CIRCUIT

A polyphase wattmeter connected by shunt and series transformers to a two-phase system is shown in Fig. 6. It is evident that the left hand side of the meter measures the power in phase *A* and the right hand in phase *B*. In this and following diagrams, power transmission is in the direction indicated by the large arrow.

Fig. 7 shows the connections of a polyphase wattmeter for measuring power in a three-phase system. This use of a polyphase wattmeter is identical in principle with the well known two-wattmeter method of measuring three-phase power, the only difference in application being that in this case the two wattmeters are replaced by

one polyphase wattmeter, which requires only a single reading to determine the power in the entire system. It is thus seen that a polyphase wattmeter operates perfectly on either two or three-phase circuits. The meters are calibrated to allow for transformer ratios so that, although the current actually passing through the current circuit is only five amperes and the e.m.f. applied to the e.m.f. coil is only 100 volts, the meter may measure any desired power.

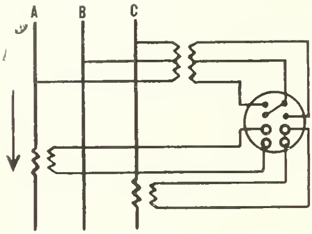


FIG. 7—POLYPHASE WATTMETER IN THREE-PHASE CIRCUIT

This discussion applies primarily to indicating meters, but a similar treatment applies equally well to integrating and graphic recording meters. In integrating meters the binding posts are so nearly in the same positions as here indicated that they will readily be recognized. The binding posts of graphic recording wattmeters are arranged in a single row at the bottom, as shown in Fig. 8.

Power-Factor Meters—These meters have one current circuit for each phase but only a single e.m.f. circuit. The e.m.f. leads are brought out at the top and the current leads at the bottom in the same manner as for wattmeters. The dial of the round type power-factor meter has an upper and a lower scale and the pointer indicates on the upper scale if the power is in the normal direction and on the lower scale if the power is reversed. The connections of a single-phase power-factor meter are shown in Fig. 9. The currents in the e.m.f. and current circuits must be in the same direction to indicate power in the normal direction.

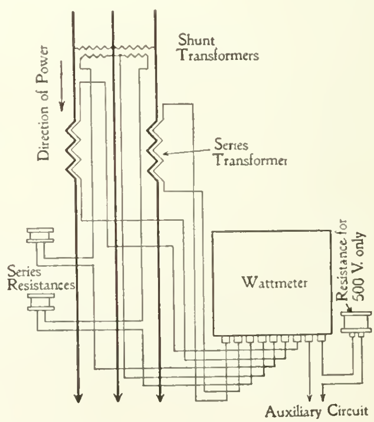


FIG. 8—GRAPHIC RECORDING WATTMETER CONNECTED TO CIRCUIT (REAR VIEW)

In Fig. 10 the connections for a two-phase power-factor meter are shown. This meter has two current circuits, one whose leads are brought out to the left and middle lower binding posts, and one to

the right and middle lower binding posts. The e.m.f. circuit is connected across one phase of the line. This must be the same phase as the left hand current circuit.

As appears in Fig 11, only two series transformers are required for a three-phase power-factor meter, although there are three series circuits. This is because the series circuits are Y-connected, and in three-wire systems the resultant of two lines is the same as the third. The effect is therefore the same as if each circuit of the meter had its own transformer. Designating the conductors of the three-phase system by *A*, *B*, *C*, if the series transformer on line *A* connects to the left hand side of the power-factor meter, while the one on *C* connects to the right hand side, and the common transformer connection is to the middle binding post, then the e.m.f. circuit must be connected to the *A-B* phase.

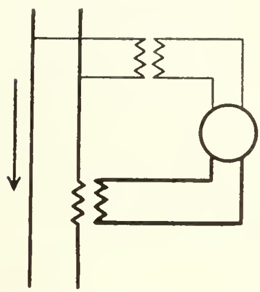


FIG. 9—CONNECTIONS FOR SINGLE-PHASE POWER-FACTOR METER (REAR VIEW)

With this, as with the two-phase meter, to indicate power in the normal direction, the current must flow in the same direction in the e.m.f. coil as in the left hand current coil and the direction in the right hand current coil must be opposed to that in the left hand current coil. Here again it is assumed that the sequence of phases is right, but this must be determined experimentally. In this case the wrong sequence would not only make a lagging current indicate leading, but it would also change the numerical value of the power-factor. If a single-phase or polyphase power-factor meter indicates reverse power, it is necessary only to reverse the e.m.f. connections to make it indicate normal power.

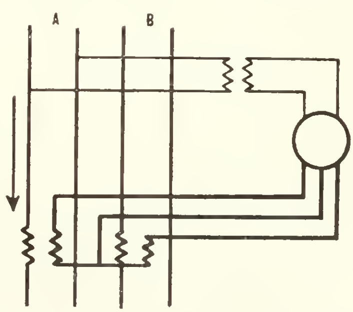


FIG. 10—CONNECTIONS FOR TWO-PHASE POWER-FACTOR METER FOR FOUR-WIRE CIRCUIT (REAR VIEW)

Figs. 12 and 13 show the connections of two-phase and three-phase graphic recording power-factor meters. In addition to the terminals that would be on indicating meters they have the auxiliary control circuit. Graphic recording meters should be connected, as are indicating meters, so that the current in the e.m.f. circuit is in the same

direction as that in the left hand current circuit. Instead of having the e.m.f. terminals at the top and the current terminals at the bottom, all leads are brought out at the bottom.

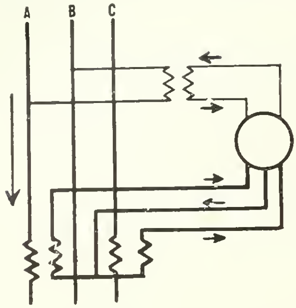


FIG. 11—CONNECTIONS FOR THREE-PHASE POWER-FACTOR METER ON THREE-WIRE CIRCUIT (REAR VIEW)

SUMMARY

1. Alternating-current lines having series instruments may be considered positive if there is a return line that is considered negative. Direction of current is then the same as direction of power transmission.

2. Direction of external current from the secondary of a shunt or series transformer is the same as if the secondary circuit connected directly to the corresponding primary terminal.

3. For normal action of any standard type of meter, corresponding e.m.f. and current circuits should have currents flowing in the same direction.

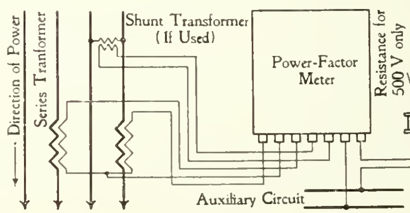


FIG. 12—TWO-PHASE GRAPHIC RECORDING POWER-FACTOR METER (REAR VIEW)

4. On standard types of meters having both current and e.m.f. circuits, current circuits are brought out at the bottom and e.m.f. circuits at the top, except on graphic recording meters which have both e.m.f. and current connections at the bottom.

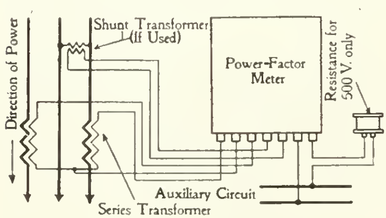


FIG. 13—THREE-PHASE GRAPHIC RECORDING POWER-FACTOR (REAR VIEW)

5. In polyphase wattmeters, e.m.f. circuits are above corresponding current circuits.

6. In power-factor meters, e.m.f. circuits should be connected across the phase whose current passes through the current circuit on the left side as viewed from the rear.

A NEW TYPE OF FRICTION BRAKE

H. D. JAMES

ALTHOUGH at first thought the brake may seem to be but a small detail in the construction of a crane, a hoist or other device, a closer examination will show that it is a very important item and one that may cause a great deal of trouble if improperly designed. The brake consumes mechanical energy in its friction surfaces and develops heat which must be radiated. The writer, together with Mr. W. A. Paris, recently conducted a series of experiments extending over eighteen months to determine the best material to use for the friction surfaces in brakes. Endurance runs were made with cast iron shoes and with shoes lined with wood, fibre, lignum-vita, etc., on both cast iron and steel wheels. The best combination proved to be a cast iron shoe bearing on a cast iron wheel. Under heavy pressure the co-efficient of friction was 0.3 and the wear on the brake wheel about one-sixteenth of the wear on the shoe. Cast iron shoes on cast iron wheels have been used for many years on freight cars and for street railway work where the service is more severe and continuous than for most industrial applications. One advantage of using metal shoes bearing against a metal wheel, is the increased radiating surface obtained. If an insulated lining is used, the heat from the rim of the wheel is not conducted directly to the brake shoe. This makes it necessary for the wheel to radiate most of the energy dissipated. Or if a combustible lining is used, the permissible heating is limited and a much larger brake wheel must be used to absorb a given amount of energy. These limiting conditions are obviated when a cast iron shoe is employed. Radiation may be improved by using a brake wheel ribbed on the inner side of the rim and provided with fans for driving the heated air away from the motor bearings. The brake shoes should be provided with deep ribs to assist in radiation as well as to make them very stiff. Such a brake can be operated at a temperature which will turn cast iron a blue color without, in any way, injuring the parts.

The magnet for operating the brake may be mounted at one side of the wheel and separated from the wearing parts by an air space so that the heat generated by friction will not be communicated directly to the magnet. The usual method of suspending brake shoes causes them to exert an unequal pressure upon the brake

wheel, because the resultant pressure produces a turning moment around the point of suspension, the shoes wear unequally and the ends have a tendency to dig into the wheel when the brake is first applied, thus causing a severe strain on the motor shaft. This defect has been overcome by making the brake shoe stiff so that the static pressure is uniform and by selecting a point of suspension such as to eliminate the turning moment on the brake shoe. If the pressure is uniform and the surface of the shoe is considered divided into a number of equal strips, the retarding force of each strip is the same and may be considered as concentrated at the center of the strip, provided the number of strips is large. Selecting two strips, *1* and *4*, Fig. 1, the retarding force may be represented in amount and direction by the lines *1-a* and *4-b*, each at right angles with the line drawn from the center of the wheel to the center of the strip. Using a point of suspension *C*, it may be seen that force *1-a* tends to turn the shoe counter-clockwise around the point *C*, having a turning moment equal to $1\text{-}a \times cd$, while the force *4-b*, having a moment equal to $4b \times ce$, tends to turn the shoe clockwise about point *C*. It is evident that point *C* may be so located that the sum of the moments for all the strips tending to produce counter-clockwise rotation is exactly balanced by the sum of the moments of those tending to produce clockwise rotation and that the resultant pressure on the point of suspension due to the upper part of the shoe will be represented by a line such as *Ra*. In the same way the turning moments about point *C* for the lower part of the shoe will balance each other and produce a resultant pressure on *C* represented by a line

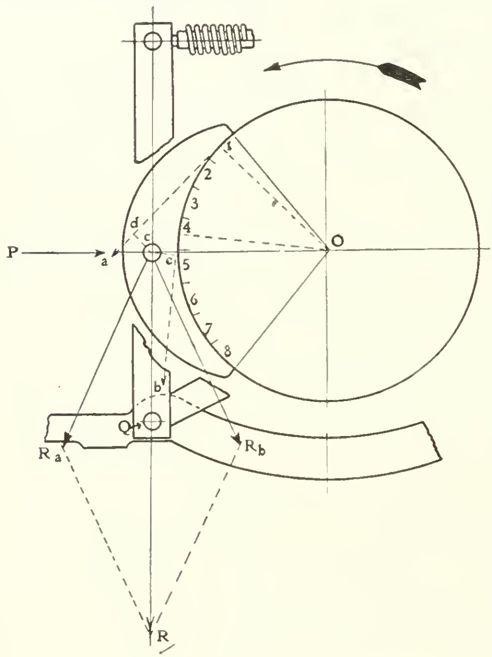


FIG. 1

Rb. The total resultant pressure of the shoe on point of suspension *C* is represented by *R* which acts directly along the brake beam and through its pivot *Q*. There is, therefore, no tendency for the beam to turn about point *Q*, thus increasing or decreasing the pressure of the shoe as a whole against the wheel. If the point *C* is located in the manner described, it insures a uniform pressure per square inch on all parts of the brake surface and freedom from any turning tendency about points *C* and *Q*, and this is true for rotation in either direction. The results of this method of suspension are as follows:

a—The shoe is free to turn and find a true seat on the wheel.

b—The pressure of the shoe against the wheel is uniformly distributed.

c—The retarding force acts directly along the brake beam and in line with it.

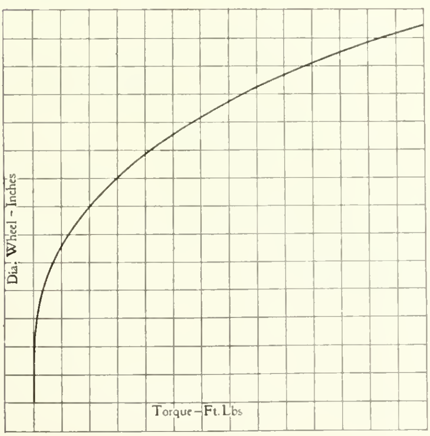


FIG. 2

There is no tendency for the ends of the shoes to press harder against the wheel and thus wear away faster, and there is no tendency or possibility of one shoe pressing harder than the other, thus producing a side thrust on the shaft bearings. This insures an even wear on the shoe and wheel and long life for both.

The relation between the diameter of the wheel and the torque exerted by the brake is expressed by the following formula:—

$$D = 24 \sqrt[3]{\frac{1}{144\ B \times C \times f \times p}} \times \sqrt[3]{\text{Torque}}$$

where, *D* equals diameter of wheel in inches; *B* equals angle (in radians) covered by two shoes; *C* equals width of wheel divided by the radius; *f* equals co-efficient of friction, and *p* equals pressure in lbs. per sq. in.

By assuming fixed values for *B*, *C*, *f* and *p*, the curve shown in Fig. 2 was plotted. This shows that for small wheels the torque increases very slowly with the diameter of the wheel. As the size

of the wheel approaches eighteen or twenty inches, the torque increases more rapidly than the size of the wheel, so that large brakes are more compact than small ones. The cast iron brake can be operated with very small clearance between the wheel and shoes, a fact which assists in reducing the size of the magnet. The pressure between the wheel and shoes is applied by means of a helical spring located over the wheel and connecting the brake beams as shown in Figs. 3 and 4. The pressure of the shoes against the wheel can be adjusted by changing the spring tension. This spring, at the same time, lifts the plunger of the magnet upwards away from the stationary core by means of the toggle members. In releasing the

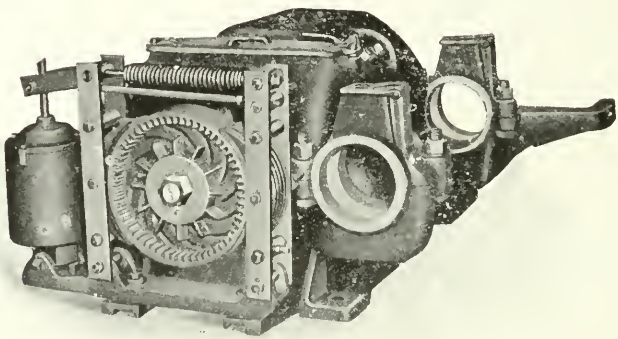


FIG. 3—FRONT VIEW OF BRAKE ATTACHED TO A MOTOR

brake, current in the magnet coil draws the plunger down, the spring being stretched just enough to clear the shoes from the wheel.

As the movement of the brake shoes and spring is very small, there is practically no stored energy in these parts. The plunger of the magnet, however, is large and moves through a considerable distance, so that there is a decided tendency for a hammer blow, when the brake shoes are applied to the rim of the wheel. A "lost motion" device, however, allows the plunger to continue to move upwards without exerting any pressure on the brake shoes. In this way the stored energy in the moving parts of the brake is allowed to dissipate itself without causing any excessive pressure on the brake shoes. To determine the amount of excessive pressure on the brake shoes, due to the stored energy of the moving parts of the magnet, tests were made on brakes, without provision for relieving

this stress. The results showed that from two to four times the normal torque of the brake was exerted at the moment the brakes were applied. These tests were made with electrical recording instruments, the brake wheel being attached to a four to one variable speed motor, so that the readings could be obtained over a wide range of speed and the variable factors eliminated.

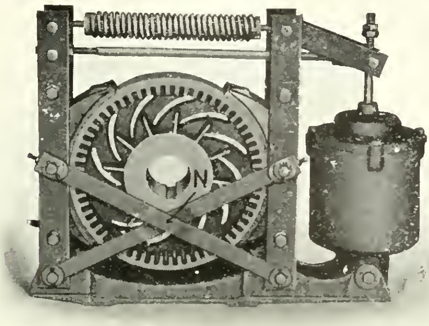


FIG. 4—REAR VIEW OF BRAKE

In order to make a metal brake shoe properly adhere to the surface of the brake wheel, an unusually heavy pressure is required. Tests showed that the minimum amount of wear is obtained when the brake shoes are designed for the maximum pressure which can be used without cutting This means that a large amount of braking power is obtained with a comparatively small wheel, but a large magnet is required to exert this pressure. By making the magnets of steel and ribbing the outside surface, very much better results can be obtained than with cast iron magnets, having a smooth surface. These magnets are entirely enclosed and all of the heat must be radiated from the external surface. The difference in temperature between the outside shell of the magnet and the coil depends upon the design of the coil and of the arrangement of the air space between the coil and the magnet. A number of careful experiments were made and it was found that considerable variation was experienced in these differences of temperature, due to different arrangements of the coil. The best results are obtained by packing the coil in an insulating compound which is a good conductor of heat. The difficulty with this arrangement becomes evident when the coil is to be changed or the insulation becomes grounded. Coils are ordinarily fastened into the frame of the magnet so that they can readily be renewed. Where it is necessary to overload a coil, the additional heating can be taken care of by filling in the air space between the magnet and the case by a special insulating compound.

CIRCUIT-INTERRUPTING DEVICES—VI

OIL CIRCUIT-BREAKERS

H. G. MacDONALD

GENERAL

THE development of large power stations and high tension transmission systems has necessitated the design of apparatus to safely and conveniently handle large currents at the high voltages which must be employed in these large systems. The earliest systems employed low voltages and the amounts of power were so limited as to be satisfactorily controlled by fuses. As capacities increased fuses were found to be inadequate to protect the circuits and some other method had to be devised. The carbon-break circuit breaker met the requirements and held the field until a new condition was encountered in the increased voltages of more modern practice. A partially successful attempt was made to take care of the moderately high voltages at first employed by means of carbon-break circuit breakers having long swinging arms and providing excessively long breaks when the apparatus opened, the circuit being broken by drawing such a long arc in the open air that it broke merely from inability to maintain itself over the distance. A three-pole circuit breaker of this type is shown in Fig. 1. On account of the long arcs made by these circuit breakers it is rather dangerous to place other apparatus near them and hence it is necessary to have large clearances and valuable space in the power station must be left vacant that could otherwise be utilized to advantage. As voltages have increased it has become imperative to find some means of rupturing the arc incident to the opening of a high tension circuit within a limited space. This problem was solved by the introduction of the oil circuit breaker in which the circuit is ruptured in a compartment or receptacle filled with oil, the oil providing the means of extinguishing the arc within a limited space. So successfully has the oil circuit breaker met the conditions that it is practically the only type used to control high tension currents. Furthermore, its adaptability to special requirements is such that it has invaded the field formerly held solely by the carbon-break circuit breaker and has become its successful rival. The fact that upon opening the oil circuit breaker the arcing takes place entirely under the surface of the oil, there being no flash in the air, makes it particularly useful in mills, mines

or other places where the air is full of explosive dust or where there are inflammable gases present in the air. In designing low voltage circuit breakers for this service it has been found that it is possible for the oil circuit breaker to compete with the carbon-break circuit breaker in price as well as in performance. Figs. 2 and 3 are two views of a comparatively low-voltage circuit breaker of very moderate cost.

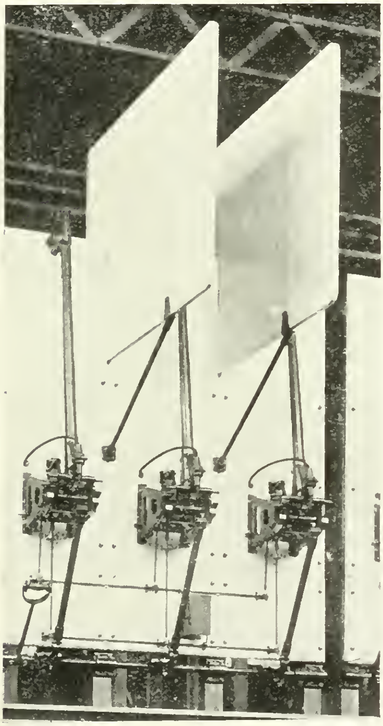


FIG. 1—THREE-POLE AIR-BREAK CIRCUIT BREAKER FOR HIGH VOLTAGE SERVICE

When closed the swinging arm makes contact on metallic jaws. On opening, the arcing takes place on carbon brushes as in the low voltage types of carbon-break circuit breakers. Marble barriers are provided to prevent the long arcs from flashing across from one pole to another.

The excellence of oil both as an insulating and as an arc-suppressing medium makes possible very compact apparatus and effects a great economy of space as compared with the air-break types. When it is considered how the value of distances under oil as regards puncture voltage and creepage voltage is increased over that in air, some idea of the saving in insulation distances may be had. The efficiency of oil as an arc-suppressing medium is due principally to its cooling effect upon the arc and to its exclusion of air or oxygen, the former corresponding to pouring water on a flame, the latter to removing the fuel. To insure a plentiful supply of cool oil at the point of arcing, the contacts are sometimes arranged so that a jet of oil is thrown against the portion of the contact on which the arcing occurs, this jet having the additional function of wiping the arc off of the contact piece. To insure the exclusion of air from the arc a liberal supply of oil is provided above and around the point where the disturbance takes place. The qualities essential in a good oil for use in oil circuit breakers are high voltage break-

down, i. e., good insulation, high flashing and burning points to reduce fire risk, small evaporation, and small sedimentation.

In the design of oil circuit breakers there are many considerations entering into the determination of the form which the apparatus will take. With one designer the question of facility of insulating certain parts may decide the general form of the apparatus; with another, the governing feature may be the disposition of the arc to rise, while in another case the requirements of the installation will determine the design. In general, howevr, the voltages to be handled, the amount of power to be interrupted and the conditions of installation and operation will govern the form which the apparatus will take. The circuit breaker must be substantial mechanically, both to withstand the wear and tear of operation, especially where electric or pneumatic operation is employed, and to withstand the strains resulting from the explosive effect of the arc. This latter may be sufficient in circuit breakers handling large capacities to seriously damage, if not entirely destroy the apparatus if it is not sufficiently strong to resist the strain. The insulation must be of a permanent character which will not deteriorate, for instance, by the action of the oil, or by ozone, which will nearly always be present where high tension currents are handled and static discharges are in evidence. All mechanism should be as simple and reliable in action as possible, as any failure may have much more serious results than in the case of low-tension, small capacity apparatus. The action of the circuit breakers in making and interrupting circuits must be posi-

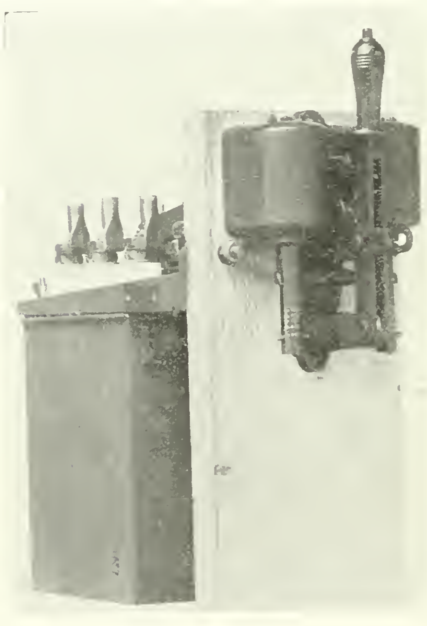


FIG. 2—THREE-POLE OIL CIRCUIT BREAKER FOR LOW VOLTAGE SERVICE

Trip coils are provided for opening electrically.

tive and rapid, as the effectiveness of the device is largely due to the quickness with which the circuit is opened.

There is a difference of opinion among the various manufacturers in regard to the relative values of certain points of design. For instance, one make of apparatus has the point at which arcing occurs far down toward the bottom of the oil receptacle to insure a large amount of oil above the arc and a pressure to force the oil into the space or bubble formed by the arc. Another equally successful design has the contacts relatively near the surface of the oil so that the break may take place where the oil is pure and clean, any sediment in the oil naturally settling to the bottom of the tank, and lowering the insulation value of the oil in that region only. The latter design also claims a quicker relief of the pressure due to the explosion of the arc, the bubbles of gas passing quickly into the air with less disturbance of the body of the oil. Both of these types have the contacts moving vertically. In the former the moving contact is drawn up to open the circuit, in the latter it drops down. Still another manufacturer makes a circuit breaker which opens horizontally, the moving contact revolving around a central pivot and moving away from the stationary contact. The claim for this type is that the disturbance is distributed and not concentrated in a vertical plane as when contacts move vertically. Also, the arc tends to flare upwards and increase in length, giving a longer path than when contacts are placed one above the other.

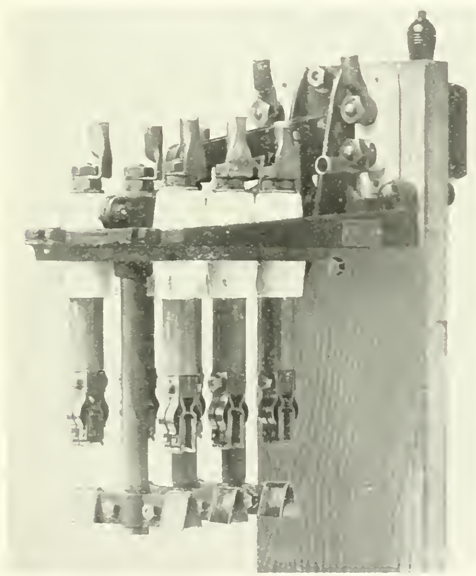


FIG. 3—REAR VIEW OF CIRCUIT BREAKER SHOWN IN FIG. 2 WITH CASE REMOVED

Again, one manufacturer places each terminal in a separate receptacle and bridges between the two receptacles of each pole with

a yoke carrying the moving contact plungers, thus confining each individual break and therefore each individual arc in a separate and isolated compartment. In other makes both terminals of a pole are placed in the same receptacle, the contour of the receptacle being such that the two terminals are practically in separate compartments as far as concerns the possibility of an arc communicating from one terminal to the other is concerned. This latter arrangement encloses all live parts in the oil chamber while in the former instance the bridging yoke and plungers which are live parts are outside the receptacle.

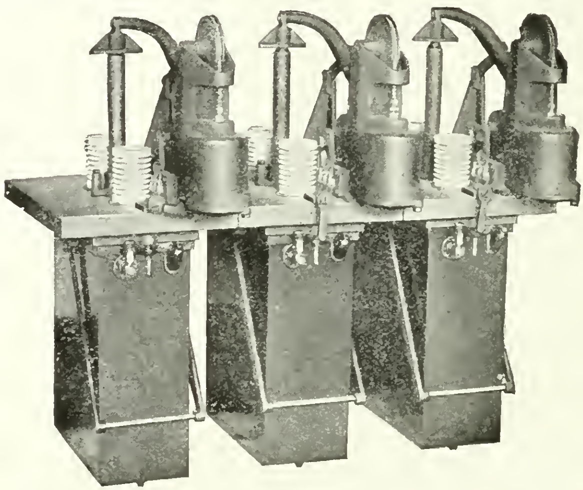


FIG. 4—THREE-POLE ELECTRICALLY-OPERATED OIL CIRCUIT BREAKER FOR HIGH VOLTAGE SERVICE

The wide variation in service to be provided for makes it difficult to follow any one line of construction throughout the entire field to be covered. A design which will be both cheap and efficient for a low capacity breaker may be entirely unsuitable for large capacities. For instance, in a low voltage non-automatic oil switch it is entirely practicable to take a simple knife switch and submerge it in an oil tank and provide suitable levers for operating the switch. This is the cheapest and most reliable piece of apparatus made for low-voltage non-automatic service. It would be entirely impracticable to try to use such a device on high tension work or where automatic operation is required.

In high tension apparatus it is highly desirable that as far as possible all live metal parts should be protected against accidental

contact. Nearly all designers, therefore, follow the practice, to a greater or less degree, of surrounding live terminals, leads, etc., by some good insulating protection such as porcelain bushings or similar covering. In one type the live terminals are placed within the cups of the porcelain insulators on top of the circuit breaker base.

It will readily be appreciated that a circuit breaker to handle satisfactorily 100 000 kw at a voltage of say 35 000 volts must be of a very substantial nature and that too much care cannot be exercised in installing and providing all possible precautions to insure successful operation. Where large amounts of power are to be handled, especially in cases of large power-houses, the circuit breakers are usually built into the structure walls which form barriers between the poles of the circuit breakers and effectually prevent an arc on one pole from communicating to adjacent poles or circuits. Fig. 5 shows an installation of circuit breakers in which the leads from the high-tension terminals are carried in ducts built into the wall at the rear of the apparatus. The cells for the several poles are closed by removable doors, so that any disturbance occurring on any individual circuit is localized and prevented from spreading.

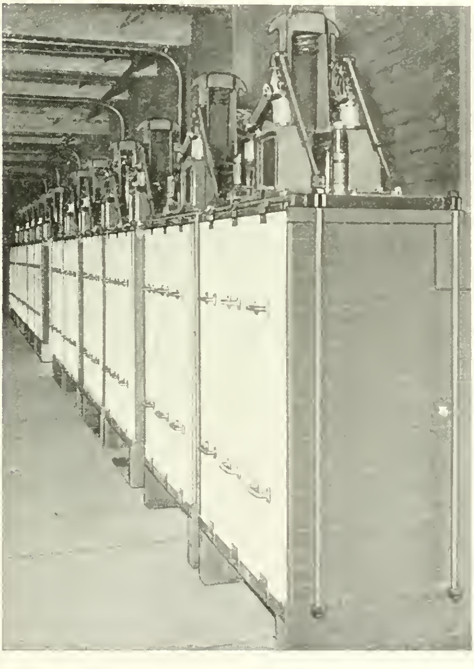


FIG. 5—INSTALLATION OF LARGE CAPACITY, HIGH VOLTAGE, THREE-POLE ELECTRICALLY-OPERATED OIL CIRCUIT BREAKERS

Each circuit breaker is provided with a separate masonry compartment for each pole.

With circuit breakers for the higher voltages it is the general practice to supply the overload coils with current from the low tension secondaries of series transformers whose primaries are con-

nected in the high tension line. This makes the insulation of these coils very much simpler than if they were energized at the line voltage. It removes the danger to the attendant, who must from time to time change the setting of the trip coils and in the case of remote-controlled circuit breakers calibrations may be made at the switchboard, as all high tension wires are kept away from the board. It also adds greatly to the flexibility of the circuit breakers as they may be used in connection with various types of relays, such as,—time limit action, action on reverse current, on no-voltage and numerous others, thus permitting the action of the circuit breaker to be modified to suit the very diverse requirements met with in modern practice. On circuit breakers for the low voltages and small capacities it is entirely practicable from mechanical and insulation standpoints and highly desirable from the standpoint of cheapness, to energize the trip coils at line voltage and thus do away with the more or less expensive series transformers. However, even in these the construction is such that when so desired the series coils can be replaced with coils energized either from transformers or other exterior sources of supply. The general practice followed as to the number of overload coils is to provide one coil for a single-phase circuit breaker and two coils for a two-phase or a three-phase circuit breaker. On a three-phase line this does not afford entire protection and in many cases where the coils are fed from transformers, one transformer per phase is used, the three being connected to the two trip coils, so that trouble on any line will cause the circuit breaker to trip.

In high tension work it is usually desirable that all phases of a circuit be opened simultaneously. It is, therefore, very essential that manually-operated circuit breakers in particular, be equipped with the "non-closable-on-overload" feature, as there is not the alternative which is often available in carbon-break circuit breakers, where the poles operate separately. In such a case it is impossible to hold the circuit breaker closed when there is a disturbance on the line as, after one pole of a phase is closed, upon throwing in the other, the first circuit breaker will immediately trip out. For this reason practically all manufacturers unite in providing this feature or its equivalent on both manually and electrically-operated circuit breakers.

As intimated previously, it is usually desirable to keep all high-tension wires and apparatus away from the switchboard where attendants must be constantly employed. This becomes imperative where extremely high voltages are employed. The remote-control

circuit breaker accomplishes this result. The main current-carrying mechanism is mounted in the high tension structure, the control mechanism alone being mounted on the switchboard. In the case of manually-operated circuit breakers this control mechanism consists of a suitable operating handle, which is connected to the circuit breaker by rods and levers, sprockets and chain, or pulleys and wire cable. In the case of electrically-operated circuit breakers the control apparatus consists of some form of switch of sufficient capacity to handle the current required in the operating device, whether motor or solenoid. As the circuit breaker itself may be entirely out of sight of the switchboard some indication must be provided to show the operator the condition of the current-carrying mechanism at any moment, whether open or closed and if open, whether it has been tripped by an over-load or opened by an attendant. In manually-operated apparatus this may usually be indicated by the position of the handle on the switchboard or it may be done by means of colored lights or other visual signaling devices or by the ringing of a gong. The colored light method is the one most generally used in connection with electrically operated circuit breakers.

THE ROTARY CONVERTER IN GREAT BRITAIN

THOMAS FRASER

IN spite of the many advantages of the rotary converter over other types of converting apparatus, there has always existed in Great Britain a strong prejudice against its use. This prejudice is undoubtedly due to the unsatisfactory operation which was experienced with certain rotaries of continental manufacture, which were installed several years ago. The prejudice against the rotary converter appears, however, to be disappearing in view of the excellent service now being given by the converters of modern design. The advantages which the rotary converter possesses over other types of converting apparatus are, briefly, high efficiency, great over-load capacity and low voltage on the rotating element. The writer recently had occasion to put into service a rotary converter whose rating is as follows: 500 kw, six phase, 25 cycles, 500/600 volts, 500 r.p.m. It is provided with an alternating-current booster, and is started from the alternating-current side. The transformer for supplying the converter is of the oil-cooled, three-phase type with a 6 500 volt star-connected high-tension and 385 volt double star-connected low-tension winding. The method of starting is extremely simple and is performed by means of a controller with two steps only: the first step impresses one-fourth voltage and the second step full-voltage. The field is not split up, but connected across the armature through a variable resistance and a reversing switch. The converter pulls into synchronism at the first notch, and if the polarity is wrong it is readily reversed by reversing the field. This causes the converter to slip a pole. The reversing switch is then thrown to its original position, and the polarity is right. The controller is then moved to the running position and the machine brought up to speed and connected to the direct-current bus-bars.

By means of the booster the direct-current voltage may be varied from 460 to 600 volts at any load, and throughout this range the power-factor can be maintained at unity or can be made to lead. This apparatus is shown in Fig. 1, which is made from a photograph of a 500 kw rotary converter with a two-point controller for starting, which was supplied to the Glasgow Corporation. Both the converter and the booster are provided with a series winding for compounding. The ability to vary the power-factor independent of load or voltage, is a great advantage, and many large plants which have a

low power-factor due to the use of induction motor-generator sets are now considering the installation of rotary converters in order to improve their power-factors.

On another occasion, the writer was present at the official test of two 700 kw rotary converters. These machines were rated as follows: 700 kw, six-phase, 40 cycles, 480 volts, 480 r.p.m., compound-wound. The machines were loaded back on each other and tested up to 100 percent overload, in addition to the endurance test at full-load. They were sparkless throughout the entire range of loads with fixed brushes. While running at full-load with full series field, the circuit breaker of one machine was opened on the alter-

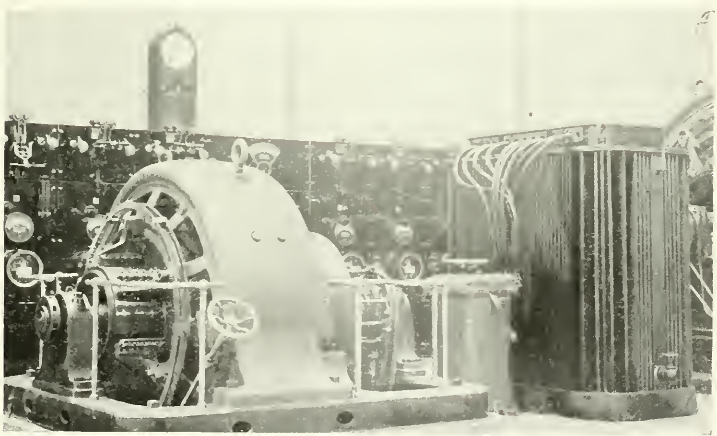


FIG. I

nating-current side to see if there was any tendency to race, but there was no appreciable rise in speed.

Still another test made by the writer to demonstrate the ability of the high frequency rotary converter to operate successfully under traction conditions was as follows: The machine was rated at 300 kw, three-phase, 60 cycles, 550 volts. The test was started by throwing on and off small loads. These were gradually increased up to 300 percent over-load. This load was thrown on and off some 20 or 30 times and there was not the slighest tendency to flash over and very little sparking took place. Loads up to 100 percent over-load could be thrown on and off with no sparking whatever.

PROTECTIVE RELAYS (Cont.)

M. C. RYPINSKI

ALTERNATING-CURRENT OVERLOAD AND REVERSE CURRENT—SINGLE-PHASE

INVERSE TIME ELEMENT ACTION

THE problem of protecting alternating-current circuits operating in parallel against a reversal of the flow of energy has been one of the most difficult ones in the design of alternating-current power systems. For this purpose relays have been employed to operate electrically-controlled circuit breakers, these relays being of a type that will operate upon reversal of current. Heretofore, two general types have been available.

The first type consisted of some form of magnet wound with two coils, through one of which current proportional to the voltage passed and through the other, current proportional to the line currents. Under normal conditions these coils oppose each other, but when the energy reverses their effects are additive, thus closing trip contacts and operating the circuit breaker. This scheme is defective on account of the fact that short-circuit conditions reduce the power-factor and voltage to a low value and consequently the relay cannot develop sufficient torque to operate.

The second type of relay consisted of a wattmeter fitted with moving contacts which could be adjusted to trip the circuit breaker at any predetermined load in true watts in the direct overload direction or in the reverse power direction. Although somewhat better than the first mentioned type of relay, it still had the fundamental defect that when the voltage or the power-factor became low, the torque developed was not sufficient to enable the wattmeter to operate as its torque was proportional to the true watts.

The ideal relay for such service should consist of such a wattmeter type relay modified so that it would have practically the same torque at low power-factors as at high power-factors and it should be operative when the voltage becomes zero. It should have the additional feature of an inverse time element action so as to exercise a selective influence and trip out the circuit in trouble without interrupting those circuits not affected and also to prevent interruption of service due to the flow of synchronizing currents between machines or to overload currents due to temporary grounds or short-

circuits. The type of relay herein described meets these conditions to a remarkable degree.

Reverse current relays for alternating-current circuits are designed to operate when the direction of the flow of energy is reversed from that required for normal operation. In actual practice they are principally used to guard against trouble arising from a reversal under the following conditions:

Improper adjustment or loss of field on one of several alternating-current generators operating in multiple, when the machine

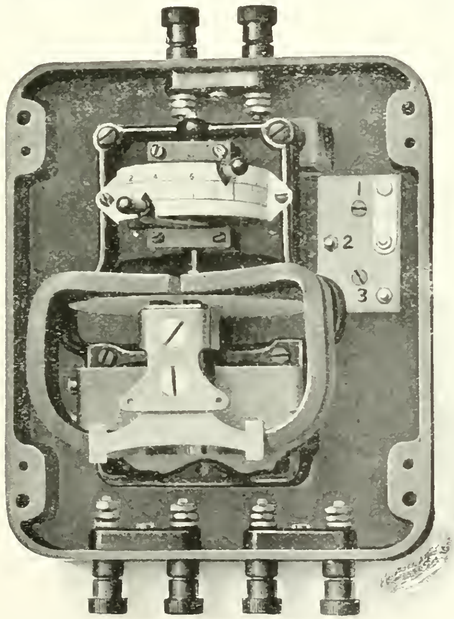


FIG. 26—SINGLE-PHASE ALTERNATING-CURRENT OVERLOAD AND REVERSE CURRENT RELAY—INVERSE TIME ELEMENT ACTION

would act as a partial short-circuit on the bus-bars.

Cutting off of power from a transmission line feeding rotary converters or synchronous motor-generator sets operating in multiple with storage batteries or other generators, in which case the rotary converter or synchronous motor would tend to run inverted and supply power to the transmission line.

A short-circuit or ground on one of several lines operating in multiple to supply power from a generating station to a sub-station. While the damaged line will be cut off from the generating station

by the action of a circuit breaker actuated through an overload relay at that point, the other lines in multiple with it would continue to supply power to the damaged line through the sub-station, until it in turn was cut out, thus interrupting service completely.

In the first case, which is of rare occurrence, the station operator can usually adjust or cut off the generator before any damage is done and without the necessity of shutting down the plant.

In the second case it is customary to use a direct-current reverse current relay. This relay in the direct-current circuit trips the direct-current circuit breaker and at the same time, may, through suitable connections, trip the alternating-current circuit breaker.

Under the third condition reverse current relays are located in the receiving station and operated from transformers in the circuit

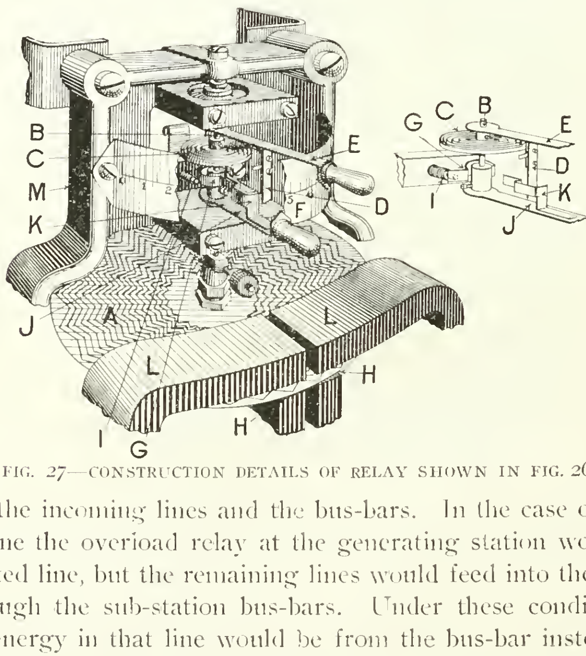


FIG. 27—CONSTRUCTION DETAILS OF RELAY SHOWN IN FIG. 26

between the incoming lines and the bus-bars. In the case of trouble on one line the overload relay at the generating station would open the affected line, but the remaining lines would feed into the affected line through the sub-station bus-bars. Under these conditions the flow of energy in that line would be from the bus-bar instead of to it and this reversal of direction would cause the reverse current relay to operate, cutting the affected line off from the bus-bars and thus entirely insolating it.

While the preceding sets forth one of the most important applications of this type of relay, it should be noted that although it operates both as an overload and as a reverse current relay, its overload setting may be made so high as to preclude tripping the breaker

in the power direction under any but most abnormal conditions, in which case the relay operates virtually on reverse current only and may be used for generator circuit protection or similar reverse current application.

In principle this relay is very similar to the induction integrating wattmeter. It involves a rotating disk attached to a shaft suitably mounted and actuated by a shifting field electro-magnetic system. Instead of driving a registering dial, however, the shaft is controlled by a spring and a moving arm is arranged to close a contact connected to the tripping circuit of the breaker. The disk

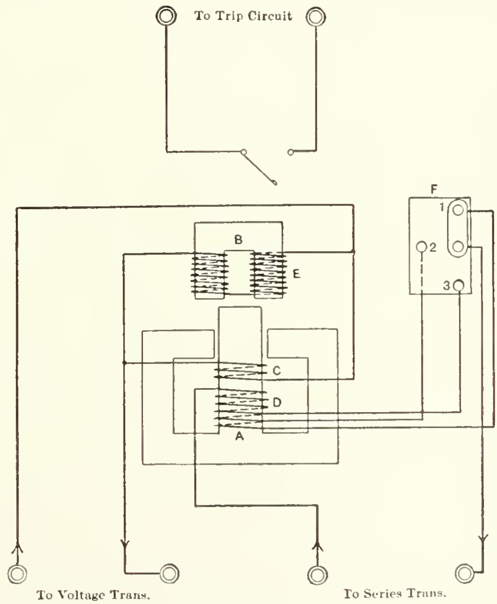


FIG. 28—CONNECTION DIAGRAM
Showing arrangement of electro-magnet.

travels through the air gaps of a pair of permanent magnets on one side and through air gaps between a pair of electro-magnets on the other. Instead, however, of the electro-magnets being wound with the usual series and shunt coils as in a wattmeter, a special winding is provided which automatically combines the influence of current alone, of voltage alone and of true watts alone. In the absence of current, the relay is in effect operative as a voltmeter. In the absence of voltage the relay is subject only to the influence of current as in an ammeter. When all these quantities are present, a very ef-

fective combination of the three elements is formed, giving the relay its characteristic properties.

The complete device with case removed is shown in Fig. 26. An outline sketch of the same relay is shown in Fig. 27, in which *A* represents the aluminum disk of the relay attached to shaft *B*. The latter is mounted in bearings in a similar manner to an induction wattmeter, that is, with ball bearing below and pin bearing above. *C* is a spiral control spring attached at its inner end to the shaft *B* and at the outer end to an adjustable arm *D* terminating in an adjustable index arm *E*, which is movable over a graduated scale *F*. *G* is a contact arm attached to the shaft *B*. The arm *G* terminates in a contact which in its travel engages a stationary insulated contact *I*, thereby completing the trip circuit. The spring, in addition to controlling the movement of the relay, serves to carry the tripping current into the movable contact. Below the index arm *E* is another index arm *J* movable over the same graduated scale. This arm is so arranged as to control and limit the motion of the contact arm *G*, but is itself limited by the position of the arm *D* attached to the index arm *E*. Index arm *E*, moved to the right, serves to increase the load setting of the relay by affecting the spiral springs so that a greater torque is required to make contact and vice versa. Index arm *J*, moved to the right serves to increase the time element by allowing the contact arm to recede from the stationary contact, under the action of the control spring and limited by the stop arm *K*, thus increasing the distance and therefore the time required to make contact and vice versa. The movement of the contact arm *G* as controlled by *J*, in the right hand direction is limited by the position of *E*, as any movement beyond *E* would cause the control spring to pass through its zero position and wind up in the opposite direction, which would tend to return the contact arm *G* to the zero position or position of *E*. *J* therefore moved beyond *E* would not give any greater time element than at *E* and a limiting stop is therefore provided on *J* as shown at *K*. *L-L* are permanent magnets, through the air gaps *H-H* of which the disk travels and on which they exert a damping or retarding influence inversely proportional to the speed of

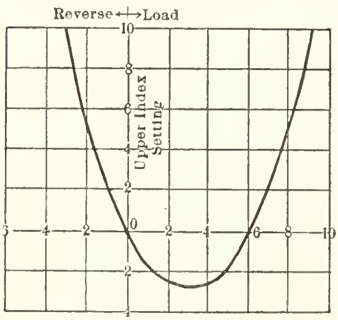


FIG. 29—CURVE SHOWING OPERATION OF RELAY WITH CURRENT AND VOLTAGE APPLIED

the disk, thereby giving an inverse time element action to the relay. Diammetrically opposite to the permanent magnets *L-L* is located the electro-magnetic system separated from *L-L* by a magnetic shielding bracket *M*. This is illustrated for convenience in Fig. 28, where *A* and *B* are the laminated iron cores of the electro-magnets corresponding in the induction type wattmeter to the shunt and series electro-magnet cores. Wound on *A* is a shunt winding *C* and a series winding *D*. On *B* is wound a shunt winding *E* connected in parallel with the shunt winding *D* in such a way that with current flowing in the power direction *C* opposes *D*, necessitating a greater current flow through *D* for a given torque developed; while with current flowing in the reverse power direction *D* is assisted by *C* and a lesser current in *D* is necessary to develop a given torque. This means that with both voltage and current applied to the relay, its action is selective, the operation on reversal of the power occurring at lower values than under the normal power condition.

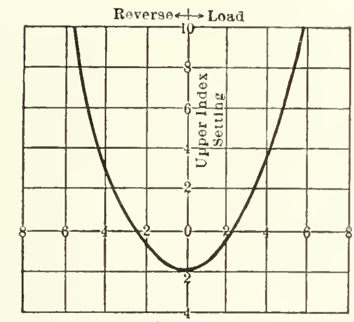


FIG. 30—CURVE SHOWING OPERATION OF RELAY WITH CURRENT ONLY APPLIED

With voltage alone applied to the relay it is still operative, but to a lesser degree due to the interaction of *C* and *E*. With only current applied, the coil *C* acts as a secondary to *D* energizing *E* and thereby creating an operating torque condition. The current coil *D* is arranged in three sections with taps brought out to the terminal block *F* on the relay base. This block comprises four terminal posts, three of which are arranged circularly around the fourth and provided with a link which can be used to connect the central terminal with any one of the three outside terminals, numbered respectively *1*, *2* and *3*. With the link connected to *1* (as shown), all the turns of *D* are in circuit and the relay is in condition of maximum sensibility, i. e., it may be set for its minimum tripping values. With the link connected to *3* only about fifty percent of the turns are in circuit and the relay is in the condition of minimum sensibility and may be set for maximum tripping values. The connection to *2* gives tripping values intermediate between *1* and *3*.

With both current and voltage applied, the operation of the re-

lay for various settings and internal connections may be obtained from the curve shown in Fig. 29, the upper index settings being plotted as ordinates and relay amperes as abscissas. The tripping values obtained will be given in terms of the current flowing in the relay, the voltage being normal and in phase with the current, i. e., 100 percent power-factor. Values for load tripping are plotted to the right of zero and for reverse tripping to the left of zero. The portion of the curve below the zero line is imaginary as settings corresponding would be below the zero on the relay scale. If the voltage be now removed the selective condition disappears and the relay operates the same in either the load or the reverse direction. A curve of this condition is given in Fig. 30. It will be noted that this curve is identical with that of Fig. 29, except that in the latter case it has been shifted by the voltage component 1.5 divisions to the right and one-fourth division down. This enables the relay to be set for high overload values and low reverse values which is the condition to be desired.

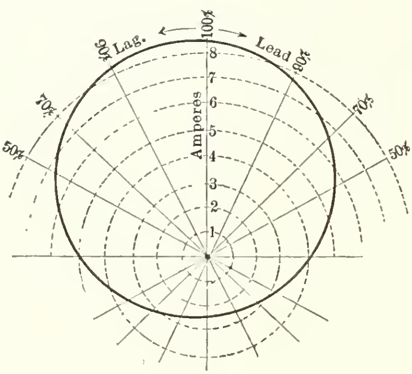


FIG. 31—CURVE SHOWING EFFECT OF VARIATIONS IN POWER-FACTOR ON OPERATION OF RELAY

The effect of power-factor variations on the relay is illustrated in Fig. 31, which has been plotted to polar co-ordinates of power-factor and tripping current, the upper index setting being fixed at 7 on the scale, the voltage normal and the internal connection *1*. It will be noted that the curve takes the form of a circle and that a change from 100 to 80 percent power-factor lagging has practically no effect on the tripping current, while from 100 to 90 percent leading the tripping current is nine percent less in the load direction and greater in the reverse direction. Thus the relay may be considered independent of power-factor variation within the limit of ordinary service conditions.

The relay has two upper and four lower terminals. The upper pair are for connection to the tripping circuit. The lower left hand pair are voltage terminals and the lower right hand pair are current terminals.

For a single-phase circuit one 100 volt relay with one series and one voltage transformer is required. For a three or four wire two-phase circuit two 100 volt relays with two series and two voltage transformers should be used. For a three or four wire three-phase circuit three 57 volt relays with three series and two voltage trans-

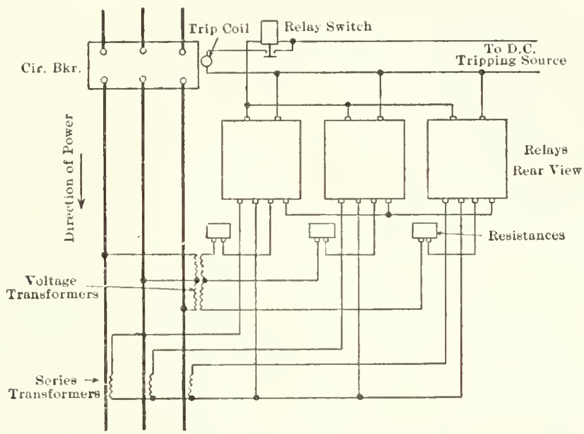


FIG. 32—CONNECTION DIAGRAM

Three single-phase alternating-current overload and reverse current relays—inverse time element action, applied to a three-phase circuit.

formers are needed. The connections to the lower terminals must always be such that with power flowing in the normal direction, through the circuit, the polarity of the left hand voltage terminal is the same as that of the left hand current terminal at any given instant. A diagram of connections of these relays as applied to a three wire three-phase system is given in Fig. 32.

(To be continued.)

EXPERIENCE ON THE ROAD

M. B. CHASE

POLYPHASE METER CONNECTIONS

IN a certain power plant complaint was made that the two polyphase meters on the switchboard measuring the same load would not check, and that the discrepancy seemed to vary with different loads. The writer investigated the cause and found that there were installed at that time one 1 500 kw generator panel and one three-phase feeder panel, the feeder panel taking the entire output of the generator. The generator panel was provided with the usual meters including a polyphase indicating wattmeter. A polyphase integrating wattmeter was mounted on the feeder panel. As there was but one generator and one feeder panel at this time, the two meters should have indicated the same load at all times. Upon checking the integrating meter with the indicating meter, however, there was found to be a decided discrepancy, the error seeming to increase as the power-factor became lower.

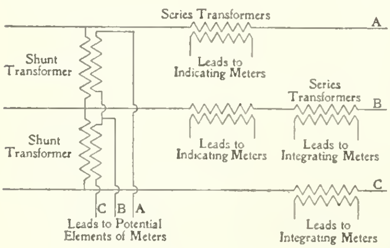


FIG. 1

A careful examination of the connections to the meters showed that both meters were operating from one pair of potential transformers connected to the main bus between phases *A-B* and phases *B-C*, as shown in Fig. 1. The series or current transformers for the indicating meter were connected in phase *A* and phase *B*, while the series transformers for the integrating meter were connected in phase *B* and phase *C*. It is at once evident that both of these connections were incorrect as with the given potential transformer connections the series transformers should be connected in phase *A* and phase *C* in each case. With the connections as originally made, one meter was running fast, while the other meter was running slow, owing to the phase relations of the potential and current transformers.

The obvious way to correct the trouble would have been to change one series transformer in each case, putting it into the proper phase. As this would have necessitated the shutting down of the plant besides considerable heavy cable work, the situation was stud-

ied carefully and it was finally decided to accomplish the desired result by changing the connections of the secondaries of the potential transformers. To obtain this result the leads *A* and *C* of the potential transformers were connected to the same element of the wattmeter as the series transformer in phase *A*, this being equivalent to taking the potential across from *A to C* for this side of the meter. The potential leads *B* and *C* were connected to the element connected with the series transformer in phase *B*. This gave the proper connection for the indicating wattmeter. For the integrating wattmeter the potential leads *A* and *C* were used with the series transformer in phase *B* and the potential leads *A* and *B* were used with the series transformer in phase C. After making these connections the meters were found to register the correct load at all power-factors.

BAD EFFECT OF A POOR GROUND ON THE SECONDARY OF A SERVICE TRANSFORMER

R. P. JACKSON

While it is common practice to ground the secondaries of service transformers as a protection against the danger incident to break-down between the high and low tension windings, it may often occur that if this connection is not carefully made and of low resistance, the ground connection will introduce an element of danger. The only safety, in fact, is in making sure that this earth connection is so effectively made and is of such low resistance that the low tension circuit cannot by any possibility reach an abnormal potential.

The arrangement of circuits and ground connections in Fig. 1 shows how actual danger to life and also a fire resulted from a poor ground when with either a good one or none at all there would have been no trouble. In this particular case the neutral of the lighting circuit and the middle point of a two-pole lightning arrester were grounded at the same pole to two plates which had been buried in the same hole in the earth. The resistance between these two ground plates was very low, but the resistance between them and the good ground of the water pipe system and the river was comparatively high. The 2 200 volt mains were carried across the river in metallic sheathed cable and the house wiring was carried in metal conduit connected to the water system. When by accident the cable in the river became grounded on one side of the 2 200 volt circuit a poten-

tial of 2 200 volts was placed on one side of the lightning arrester. This arrester then broke down and connected the ungrounded side of the 2 200 volt circuit to the lightning arrester ground plate, which practically meant that both ground plates were raised to a potential of nearly 2 200 volts above that of the river and the water system. The resistance between the plates and the water pipe system and river was high enough to prevent the flow of sufficient current to materially lower the potential delivered to the terminals of the transformer. The result therefore was that the two ground plates and the lighting circuit were at a potential of nearly 2 200 volts above the water pipes and also of the conduits of the house wiring.

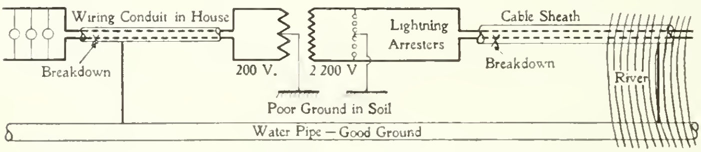


FIG. 1—ARRANGEMENT OF CIRCUITS AND GROUND CONNECTIONS

This was the cause of the breakdown which started a persistent arc that resulted in a fire. If the earth connection of the 220 volt circuit had been much better or if there had been none at all there would have been no trouble.

If, however, in conjunction with this trouble there had been a breakdown between the high and low tension windings of the transformer the only absolute safety would have been in a very low resistance and effective earth connections for the secondary circuit and no earth connection or ground whatever would have meant both a life and fire danger.

The logic of the whole situation not only calls for grounding of the secondary circuit of service transformers, but also shows that the best possible ground connection is none too good.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

54—What is the effect on a four-pole rotary converter of having one or more air-gaps larger than the others? F. C. L.

In a rotary converter having variable air-gaps under the different poles, the effect depends largely upon the type of armature winding. If the rotary converter has a two-circuit winding, the current will divide unequally between the different brushes in parallel so that some brushes may be overworked while others are underworked. In this case the variable air-gap is liable to cause sparking at the brushes oposite the poles with the small air-gap.

In a multiple circuit cross-connected winding, the cross connections serve to equalize the pole strengths in spite of the unequal air-gaps so that unless the variation in air-gap is extreme no effect will be observed in the operation of the rotary. If the armature winding is not cross-connected, the trouble will be similar to the previous case with a two-circuit winding. F. D. N.

55—I have a 7.5 kw rotary converter which is brought up to speed as a direct-current shunt motor, and when synchronized begins to hunt immediately. The circuit breaker does not open for, say, twenty seconds. When the synchronizing switch is closed, the alternating-current ammeter reads about 30 amperes and then rises immediately to 120 amperes, when the circuit breaker opens. Inductance in the form of choke coils has been used on the alternating-current side, but because the voltage was reduced so much, this was abandoned. May I ask an explanation and possible remedy? Further, I might add that the alternating-current is supplied from 60-cycle, 2 200-volt, hand-regulated, water-wheel driven alternators. The rotary and alternator are of different manufacture. F. C. L.

Hunting in a rotary converter may be caused by insufficient damper capacity in the rotary itself, by periodic variations in frequency or voltage of the supply circuit, generally caused by hunting in the governor controlling the prime mover or in excessive resistance drop between the power generator and the rotary. Each hunting trouble is a case by itself and can only be solved by experiment with the machine and circuit. In hunting troubles, an explanation can best be made after a cure has been experimentally determined. However, if the rotary is provided with heavy copper grid dampers on the poles, trouble from hunting will be practically eliminated. If the rotary was not originally built with dampers they can be added by machining slots across the pole faces. F. D. N.

56—Why are the readings of some of the power-factor meters located on the benchboard of a railway sub-station affected when a rotary converter is cut off the alternating-current bus-bars and the negative switches on the direct-current side are not opened? F. C. L.

We do not see that the switches on the direct-current side have anything to do with the matter. If a rotary converter is running and supplying either leading or lagging current to the system, disconnecting this rotary from the alternating-current lines will naturally change the power-factor of the circuit. Whether all power-factor meters are affected, or whether no power-factor meters are affected, depends entirely on the connections of the power-factor meters, that is, to what part of the circuit they are connected. F. D. N.

57—If a rotary converter rated at ten kw is run as a double-current generator, is it possible to

supply a five kw load from each side at the same time, or in other words, how can the output be made to vary from no-load to full-load? What overload can the rotary be subjected to in this case and will the effects of such an overload differ from the effects produced in a regular direct-current generator when overloaded? F. C. L.

If a rotary converter rated at ten kw is run as a double-current generator, the rating as a direct-current generator will be limited to not more than 50 percent of its rating as a rotary converter on account of commutation. A ten kw rotary converter can supply in most cases five kw as a direct-current generator without trouble from commutation. It can at the same time supply five kw as an alternating-current generator but the armature coil heating will be considerably greater under these conditions than when supplying ten kw as a rotary converter. You will note from the above that on the direct-current side, output is limited by commutation. On the alternating-current side it is limited by temperature and regulation. The regulation, however, in most cases will not be a controlling factor and will not make the operation dangerous or unsatisfactory. When operating as a rotary the alternating and direct currents subtract while in operating as a double current generator they add. The overload a rotary can be subjected to as direct-current generator varies widely with different rotaries on account of commutation characteristics. In an extreme case a rotary that will carry 75 percent overload as a rotary converter might not carry 50 percent of its rating as a generator without dangerous sparking. F. D. N.

58—On page 35 of the January, 1908, issue, the author says with reference to Fig. 3, "*CH* is direction and amount of reactance volts inserted in the compensator voltmeter circuit; *GH* is direction and amount of resistance drop inserted in compensator voltmeter circuit," etc. In Fig. 7, *A* and *B* are in series and *D* is a transformer connected in shunt to *A* and giving an e.m.f. proportional to and in step with that across *A*. This leaves me uncertain as to how the same current can give e.m.f.'s in the two coils at right angles to each other. E. E. G. R.

The current is practically the same in windings *A* and *B*, Fig. 7, but this current is the vector sum of two currents which are in quadrature. The voltage impressed on the secondary winding of the line series transformers tends to drive a certain current through windings *A* and *B*. Since *A* is non-inductive and *B* is highly inductive, this voltage is split up into two components which are in quadrature, one component overcoming the reactance of *B*. It is these quadrature e.m.f.'s impressed on the primaries of transformers *B* and *D* which produces quadrature e.m.f.'s in the secondaries of these transformers. W. N.

59—Economy of Condenser Operation—Would it be better, on account of wide variation of the volume of water required to condense the steam from a turbine due to the temperature changes of injection water and load variations, to have the circulating pump automatically controlled to furnish just the right amount of water to keep vacuum at a high point? What percent of the hp output of a turbine is considered good practice to allow for the drive of the circulating pump? H. H.

For reasonably small variations it is undesirable to vary the quantity of circulating water in a surface condenser, as at fractional loads it is better to reap the benefit of a higher attainable vacuum than to maintain the temperature constant and go on operating at fractional loads with the same vacuum that is possible with the heavy loads. This is practically true in turbine work because the turbine is more able to avail itself of the higher vacuum. The steam consumption, furthermore, is affected more at fractional loads than at full loads. In a case where a turbine would be affected three percent by a change of one inch of vacuum, the effect would be about five percent at one-half load. In some cases, however, an automatic adjustment of the volume of con-

densing water would be desirable, but the thermostats, which would be the necessary means of control, are not particularly reliable. They have never been used in practice to any material extent.

The percentage of the capacity of the turbine used to operate the circulating pump, depends entirely upon the location of the power plant with reference to the available cooling water. Generally the resistance in the condenser itself amounts to eight or ten feet, so that with cooling water suitably located, the power required for the circulating pump approximates three-fourths of one percent. The full amount of this power, however, should not be charged against operating the condenser when the exhaust steam from the engine driving the circulating pump is used in heating feed water. When properly used for feed heating without any escape of exhaust steam to the atmosphere, only about 20 percent of the steam used to operate the circulating pump is properly chargeable to the condenser. F. H.

60—Iron Pipe for Lightning Arrester Ground—It has been claimed that for a lightning arrester ground an iron bar driven into the earth is better than an iron pipe of the same length and sectional area, the reason given being that the pipe acts like a choke coil and therefore offers a resistance to the passage of the lightning discharge. If there is any difference please explain. W. J. P.

Either an iron bar or pipe will give a satisfactory ground if driven to a sufficient depth in the ground to insure good contact with permanently damp earth. The pipe might be considered as having a slight advantage because of the larger surface in contact with the earth, due to its larger diameter. In either case it is very important that the ground lead be either riveted or soldered to the grounded iron piece so as to insure perfect and permanent contact. Pipes are often used to protect the ground leads of lightning arresters mounted on poles. When used in this way they are made long enough to surround the ground wire for a depth of a few inches under ground to six or seven feet above ground. It is with this arrangement that the choking effect takes place unless the very important precaution is taken of connecting the ground wire and the pipe in metallic contact, as otherwise the arrangement of the ground wire, its insulation and the iron pipe surrounding them form a condenser which, with the high frequency discharges usually passing when the arrester operates, have the effect of very materially reducing the freedom of discharge.

61—What System of Distribution (two or three-phase), should be installed in a town of about 12 000 inhabitants, where both light and power will be taken from the same mains; the capacity of the plant to be about 700 kw, the voltage of the primaries 2 300 and the frequency 50 cycles? J. R. T.

By providing a three-phase generator and switchboard, single-phase lighting service may be supplied from two of the phases if controlled by automatic regulators; where power is used in small quantities the other phase may be employed as an independent single-phase circuit to take care of the power load. This single-phase service should be used up to the point where the load warrants the extension of the third wire from the station, after which the power can be handled three-phase. Then if the power load be increased to the point where the regulation of light is affected, the expense of a separate three-phase power circuit will in all probability be warranted. H. N. M.

62—In a multi-gap lighting arrester of the type using a resistance in parallel with the gaps, why is it that the low frequency discharges prefer one path to the earth, while high frequency discharges choose the other?

W. E. V. S.

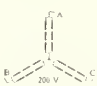
The shunt resistance, being wound inductively, will, at the time current is passing through it, have a potential across it directly proportional to the frequency of the current. If this frequency, therefore, be sufficiently high, enough potential will accumulate across the shunt resistance, due to the

drop therein, to break down the shunted gaps. Such frequencies often occur in actual lightning discharges.

R. B. I.

63—To Change an Induction Motor rated at 20 hp, three-phase, 60-cycles, 200 volts, 1 120 r.p.m., for use on a three-phase, 60-cycle, 400-volt circuit, what alterations are necessary in the connections? Please give diagrams of connections and changes, or refer to figures and diagrams previously published in the Journal. F. C.

Generally a 200-volt motor is connected with the groups of each phase arranged in two parallel series. To change to 400 volts, it is necessary to connect all of the groups of each phase in series. In the case mentioned there would be in general eighteen groups, six groups in each phase arranged in two parallel groups of



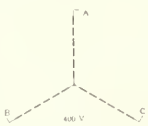


FIG. 63 (a) FIG. 63 (b)

three in series, as shown in Fig. 63 (a). For 400 volts all six groups could be connected in series as shown in Fig. 63 (b). A typical connection diagram for a three-phase, star-connected motor was given in an article by Mr. Garcelon in Vol. I., p. 49 of the Journal. G. H. G.

64—In the article on "Electric Drive of a Large Rolling Mill" in the February issue mention was made of a means of securing a larger number of commutator bars on the generator than would be called for under ordinary commercial operation. Why is it that a larger number of commutator bars are called for in this particular case?

D. D. H.

If such a connection were not employed it is evident that but one-half as many commutator bars could be used. With but half the number of bars the average voltage between adjacent bars would, in this case, be higher than is considered good practice. The speed of the armature was such as to preclude the use of a larger number of conductors and commutator bars connected in the regular way. W. A. D.

65—When the field current of a 500-volt, 60-cycle, three-phase generator is either increased or decreased why should the two wattmeter readings also change, one increasing and the other decreasing, although the total power output remains unchanged? D. MacR.

This can occur only when either there are two generators operating in parallel or a generator is operating on a line on which there is synchronous apparatus. In either of these conditions varying the field of one generator or of that of the synchronous machine will vary the power-factor of the line. Each of the two wattmeters has a series coil connected in a phase of the line. The phase which does not have a series coil is the one to which the voltage coils of the two meters are connected. The effect, therefore, of changing the power-factor by variation of the field current of the synchronous machine is to cause unbalancing of the voltages which are measured by these two coils. This causes one wattmeter to register a larger portion of the power than the other, the total amount of power, however, remaining the same.

P. M. L.

66—When using a voltmeter as a ground detector on 600-volt, three-phase circuits does the following formula hold good, the same as for direct-current circuits when used for measuring insulation resisance to ground?

$$R = r\left(\frac{E}{v} - 1\right)$$

when R = the resistance of the insulation to be determined, r = internal resistance of the voltmeter (+ the series resistance if used with a voltmeter), E = potential of circuit and v = the reading of the voltmeter. E. R. R.

Yes, provided E in the formula given is the Y voltage and not the delta voltage. Theoretically the inductance of the voltmeter enters into the question. Practically, if either R

is large compared with the ohmic resistance *r*, or if the resistance drop in the meter is large compared with its inductive drop, the inductive effect in either case is altogether negligible and the formula holds good. If it is not convenient to get the connection between the neutral of each phase, as shown in Fig. 66 (a), and the voltmeter has to be connected across phases, the value *E* in the formula should be divided by $\sqrt{3}$ or, what is equivalent, multiplied by 0.576.

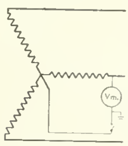


FIG. 66 (a)

67—When the two wattmeters on a three-phase circuit have the same reading, does this indicate that the power-factor is 100 percent or very close to it, no matter what kind of load the machine is carrying? D. MacR.

This would indicate 100 percent power-factor in case of balanced (equal) currents, but not in case of badly unbalanced currents. For example, assume that the current in wattmeter *A* is one-half the current in wattmeter *E*; assume that the current in *A* lags 30 degrees and so comes in phase with the e.m.f. across *A*, and that the current in *B* lags 30 degrees and so comes 60 degrees out of phase with the e.m.f. across *B*. If the e.m.f.'s are equal, the two wattmeters will read exactly the same, although both *A* and *B* lag 30 degrees. It happens in this particular case that the current in the third line, the one to which a voltage lead from each wattmeter is connected and which, therefore, does not pass through either wattmeter, lags exactly 60 degrees.

68—What is the equivalent inductance of a bank of transformers connected in delta, supposing the primary inductance to be Xp ohms and the secondary inductance Xs ohms? What would be the equivalent inductance of four banks, similar to the above, connected in parallel to a common bus? H. C. H.

It is assumed that the impedance volts are what are referred to, with a bank of three similar transformers connected in delta. The regulation of the line is determined by the regulation of one transformer. The regulation of a transformer is determined by the impedance volts. This is true for each phase of the three-phase line with the transformers connected in delta or likewise of a single-phase circuit with its single transformer. With four banks of transformers operating in parallel, the regulation would be no different than that of a single bank and would still depend on the regulation of a single transformer, the load being, of course, proportional to the number of transformers.

69—Referring to question 28 in the February JOURNAL I would be pleased to know, in addition to the answer that has been given, what is the correct way to connect two indicating wattmeters to these same series transformers, the pressure transformers being connected across the outside phases.

Where two single-phase wattmeters are used to measure three-phase power it is well to consider as positive the two lines in which the series transformers are placed, and to consider that the direction of current in these lines is the same as the direction of power transmission. The direction of current in the primary and

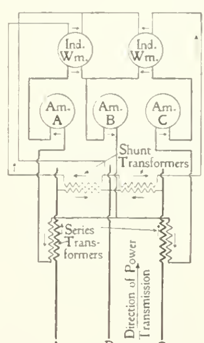


FIG. 69 (a)

secondary circuits of the shunt and series transformers would then be as indicated by the small arrows in the connection diagram, Fig. 69 (a). Assuming that a positive deflection of the wattmeter is produced when the

current flows in the same direction between the current terminals as between the e.m.f. terminals, the connections should be as shown. The e.m.f. terminals are shown at the top, and the current terminals at the bottom.

The total power transmitted by the three lines is the sum of the two wattmeter readings. The meters automatically take care of phase differences due to leading or lagging courrents. On account of this phase difference, sometimes one meter indicates negative power. In such a case if the meter has no negative scale, either the current or the voltage connections should be reversed; the total power is then the difference, instead of the sum of the two readings.

H. W. B.

70—(a) What is the consumption of fuel per horse-power or kilowatt-hour of 1, 2, 4, 6, 10 and 20 hp gas, gasoline, petroleum, or alcohol engines of the ordinary type now in the market, which are used for stationary and marine purposes?

(b) What is the lubricating oil consumption of the above engines?

(c) What is the commercial name of the grade of gasoline which is best suited to the above engines? What for alcohol? C. H. S.

(a) Above five hp size has little to do with economy. For four-cycle engines of five hp and over, one pint of gasoline per brake hp-hr. is a common figure and it is not safe to figure on anything better, with hit and miss stationary engines. The following figures may be of value:

One pint to 0.2 gal. per brake hp-hr for four-cycle kerosene engines.

0.15 to 0.35 gal. per brake hp-hr. for two cycle kerosene engines.

0.02 to 0.27 gal. per brake hp-hr for 4"x4" two-cycle gasoline boat engine.

0.18 to 0.35 gal. per brake hp-hr. for four-cycle alcohol engine.

(b) a 20-hp, single-cylinder, four-cycle engine should not require over one quart in ten hours, while a two-hp, two-cycle engine might use one gallon in the same time.

(c) Some run well on benzine, 60 or 62° Baume @ 60° F. All should run on stove gasoline, 65° Baume @ 60° F. Some require 68 to 72° Baume @ 60° F. Denaturalized alcohol, 94%, sp. gr. 0.816. M. R.C.

71—Sixty-Cycle Induction Motors Operating on Fifty-Cycle Circuits — Beside lower speed, in what ways are the operating conditions of a sixty-cycle, three-phase motor affected when operating on fifty-cycle circuits, i. e., what will be the difference in power consumption, efficiency, slip, etc.? What will be the effect of increasing the frequency? T. L. M.

The result of this increase in frequency is explained in an article by Mr. G. B. Werner, in the Journal for July, 1906, p. 403; also in an article by Mr. J. W. Welsh, in the Journal for September, 1905, p. 553. In general it may be stated that "a sixty-cycle motor can be successfully operated on fifty-cycles with about the same efficiency, slightly lower power-factor, increased starting and pull-out torgue and reduction in speed." Likewise, fifty-cycle motors can be operated successfully at sixty-cycles with about the same efficiency, improved power-factor; but decreased starting and pull-out torgue.

72—Position of Series Coils— Does it make any difference whether the series coils in a compound-wound direct-current railway generators are placed between the shunt coils and the yoke or next to the armature? R. D. J.

The nearer the field coils are to the ends of the poles the less will be the magnetic leakage. In the design of machines this leakage is taken care of by supplying additional ampere-turns in either the series or shunt coils, depending on which are located adjacent to the yoke. With strap-wound series coils it is often found more convenient to place the series coils adjacent to the yoke because of the greater space available. In large low-voltage machines a considerable saving in copper is effected by placing the series coils next to the armature because of the shorter connections required between coils. C. F. L.

73—Reversal of Single-Phase Wattmeters on Two-Phase

LOAD—A small two-phase motor is connected to a circuit which is metered by means of two single-phase wattmeters. On light loads one wattmeter runs forward while the other runs backward. Please explain this. C. I. Y.

When the voltages are unbalanced there is a tendency, on light loads, toward an unbalancing of the two phases which is augmented by the accompanying condition of low power-factor. The result is that there is a tendency for one phase to draw power from the line and by the transformer action in the secondary of the motor, to pump back power into the other phase. This explains the action of the second meter in running in the wrong direction. The effect does not occur where a two-phase wattmeter is used because, in this case, the two elements are mechanically connected and the movement of the shaft represents the algebraic sum of the power measured by the two elements. This need not be considered as an abnormal condition as it is liable to occur on light loads even with a well-designed motor. It has been found that, by increasing the size of the leads running to the motor so that they will have ample carrying capacity for the size of the motor, in general, there is a tendency towards remedying the condition by decreasing the line drop and thus equalizing the voltage of the two phases. W. B.

74—How is the copper sulphate test for moisture in transformer oil made when drying out transformers? R. D. J.

Place a small amount of anhydrous copper sulphate in a test tube and then fill the tube with oil. After shaking thoroughly, the copper sulphate will give a bluish tinge if moisture is present in the oil. The oil for testing should be from the bottom of the transformer tank. (See article on "Transformer Oil" by Mr. C. E. Skinner in the JOURNAL for May, 1904, p. 234.)

75—When a commutator is being turned down in a lathe at what speed should it run? R. D. J.

A peripheral speed of from 400 to 500 feet per minute may be used. The tool should be of the diamond shape and should be set as high above the center as it can be and yet cut with a clearance below the point. A high cutting speed with a sharp and carefully ground tool gives the best results in machining copper.

76—SELF-STARTING SYNCHRONOUS MOTOR—I understand that polyphase synchronous motors may be made self-starting from an alternating-current circuit by providing a squirrel-cage winding for the rotor, that the motor may then be started as a plain induction motor and when it is up to speed there is no current in the cage winding for the reason that there is no slip with the motor in synchronism. Is this a correct statement of the arrangemen? If not, please describe same and explain the action of the apparatus. C. I. Y.

Any synchronous motor will start itself as an induction motor when alternating current is introduced into its armature winding. Some motors will start more efficiently in this way than others, depending upon the construction of the rotating part. With laminated poles there is very little chance for the armature current to induce currents in the revolving part and relatively little torque will be developed. The rotating part with solid poles permits better circulation of the induced currents and such a rotor will develop considerably more torque than one having laminated poles. A rotor provided with a cage winding similar to the cage winding of an induction motor gives still better conditions for the development of torque as an induction motor. Therefore, when it is desired to start synchronous motors by this method, it is usual to provide a cage winding on the rotating part. With this construction it is possible for a synchronous motor to start itself and one other machine, as in a motor-generator set, taking one and one-half times the rated k.v.a. of the motor from the supply circuit. This figure assumes the use of lowering transformers to obtain a reduced voltage to start the synchronous motor. When the synchronous motor is up to speed there will be, of course, no current in the cage winding since it is ro-

tating in synchronism with the armature field. This cage winding also acts very effectively as a damper to prevent hunting. Some compromise, however, must be made in the design of the cage winding since it is desirable to have a high resistance winding for starting and a low resistance winding for the prevention of hunting. In certain cases, synchronous motors have been built with a very low resistance cage winding where the cage winding was used for the purpose of the prevention of hunting and without reference to starting performance. F. D. N.

77—What is the nature of the current and e.m.f. in the secondary of an induction coil; pulsating or alternating, and why? T. R. M.

The e.m.f. in the secondary of an induction coil is alternating. When the primary circuit is made (through the interrupter) it develops an increasing flux in the core which induces an e.m.f. in the secondary coil in a certain direction, and when the primary circuit is broken, a decreasing flux in the core results, which induces an e.m.f. in the secondary in the opposite direction. Therefore there is induced in the secondary coil an alternating e.m.f. having greater values in one direction than in the other, from the fact that the flux in the core increases from zero to maximum much slower than it decreases from maximum to zero, thus causing a greater e.m.f. to be induced in the secondary coil at the break of the primary circuit than at the make. A. P. B.

78—Effect of Power-Factor on Capacity—An electric power company has a contract to furnish 3 000 hp to a pulp and paper mill. Their current is generated by waterpower, transmitted over a three-phase line at 22 000 volts a distance of 15 miles to the paper mill where it is stepped down to 550 volts. In this contract the electric company agrees to maintain their voltage and frequency at a certain standard, but they require that the power-factor at the paper mill shall be at least 90 percent. Will you kindly explain what their reasons are for demanding that the power-factor be limited to a minimum of 90 percent and what are the elements which enter into the advisability of this high power-factor from the standpoint of the company furnishing the electricity? O. B. H.

The size of generators, transformers and transmission lines depends upon the kilo-volt amperes which they are called upon to deliver; not the kilowatts. For instance, if 3 000 hp at 50 percent power-factor is demanded by a customer, the size of transmission lines, transformers and generators will have to be made to correspond to a 6 000 hp plant. This manifestly puts an undue burden upon the company furnishing power and for that reason it is perfectly logical for them to specify that the power-factor of the load shall not be less than a certain figure and if it is less to place a penalty upon such low power-factor. P. M. L.

79—Spacing for Transmission Lines—We have 18 miles of transmission line built with a seven-foot triangle operating at 44 000 volts. When we extend this line about 30 miles would there be any reason for not building the 30 miles with a five or six-foot triangle instead of seven-foot as the 18 miles is built? H. N. C.

A five-foot triangle would give ample spacing for a line operating at 44 000 volts. There would be a slight improvement in the regulation of the line with this smaller spacing than would be obtained if the seven-foot spacing were continued throughout the entire length of the line because of a slight decrease in induction in the section having the closer spacing. The difference in regulation, however, would be practically negligible. C. P. F.

THE

ELECTRIC JOURNAL

VOL. V. JUNE, 1908 NO. 6

Temperature Ratings

It has long been recognized that electrical generating apparatus as designed and built by American manufacturers has more margin than apparatus of a similar rating designed and built by foreign makers. In other words a one thousand kilowatt generator is a considerably larger machine in the United States than it is in Germany. This difference is even greater than is indicated by the comparative tables, given in the article on "British, American and German Standards for Electrical Apparatus," by Mr. J. S. Peck in this issue of the JOURNAL, for the reason that the overload capacities demanded by the American purchasing public are considerably in excess of those necessary to conform to the standardization rules of the American Institute of Electrical Engineers.

For instance, the American Institute rules call for twenty-five percent overload for two hours on generators, and at this increased load allow fifteen degrees C. temperature rise in excess of that allowed at full-load. On the other hand, American manufacturers have, in the past, been producing, and the purchasing public demanding, generators designed to meet specifications calling for twenty-five percent overload continuously with ten degrees C. temperature rise in excess of the full-load temperature and fifty percent overload for one to two hours with twenty degrees C. rise in excess of that at full-load. This latter condition may be compared directly with the German forty percent overload for three minutes without any temperature guarantee.

It is unfortunate that the American purchaser has been educated to demand generators conforming to the above mentioned overload guarantee, since the excess in temperature over full-load conditions thereby allowed is far from logical. A generator which meets the fifty percent overload conditions will usually have ten degrees, and in some cases as much as twenty degrees to spare at full-load. The American Institute requirement is much more logical in this respect. The fifteen degrees excess temperature rise allowed for a two hour twenty-five percent overload is, within limits, what may be expected in practice with a logically rated machine.

In respect to overloads the American Institute rule is superior to the German, since the American rule fixes the excess temperature for a specified overload during a specified time; the German rule, on the other hand, does not fix any excess temperature for the specified overload. In fact, they definitely state that the overload tests must not follow a full-load test, in order to avoid over-heating.

Of the three methods of rating, the German goes to the extreme in one direction; that is, the rating given to the generator is the highest the machine can stand. The usual American practice goes to the extreme in the other direction in that a generator receives a rating which is considerably below the logical rating. The requirements of the American Institute standarization rules lie between the two and give to a machine a rational rating as well as provide a reasonable overload capacity which is limited to a reasonable temperature rise.

Speed the day when the American public will be educated to the point where they are willing to accept the reasonable and logical method of rating generators laid down by the standardization rules of the American Institute of Electrical Engineers.

P. M. Lincoln

Opportunities for New Developments in Steam Turbines

The excellent article in this issue of the Journal, by Mr. J. N. Bailey, on the subject of "Steam Turbines" should be read carefully by all engineers who may be but meagerly acquainted with the principles of steam turbine design. This type of prime mover has now acquired such general adoption in the field of power generation and is so intimately related to many branches of engineering work, that more or less familiarity with its principles becomes a necessary part of one's general engineering knowledge.

In the electrical field alone, that of driving direct-connected electric generators, there have now been installed in the United States something in excess of two million steam turbine horsepower. Coincident with this development, the use of steam turbines for the propulsion of marine vessels has become very extended, its success on ships of high speed having been well established. There are other fields, some of them still scarcely tried, in which this class of prime mover will offer striking advantages, and in which the engineer's creative talents will find ample scope. Many of the driven

machines and devices, now adapted to reciprocating engine speeds, will be designed for the higher steam turbine speeds, introducing economy in first cost and in operation, and perhaps introducing new standards of unit size and other advantages of great economic value.

There is, therefore, plenty of room for new engineers, with new conceptions; and it is to this class of readers—those who are charging and getting ready—that I specially commend the importance of this subject.

E. H. SNIFFIN

Engineering Conveniences

Any method which will accomplish a material saving in the time or labor required for engineering calculations is well worth while. Tables and curves are often used to advantage for this purpose. While a table gives exact values, it is often desirable to interpolate and also to estimate what the results will be if any of the factors are changed. For such work a curve or set of curves is more satisfactory, as they furnish a physical conception of the relative importance of the quantities. A simple curve may be read with facility by almost any one, but the more complicated charts, in which it is necessary to go through several operations to secure a result, often have the objection that they must be used quite often to be of any great assistance, and hence the simpler and more self-evident they are, the better. For occasional use, unless engineering conveniences are simple and readily applied, it is usually easier to solve directly the problems that come up, than it is to study out the method of using the auxiliary devices and to be sure that they are correctly applied.

In the article by Messrs. Stovel and Carle in this issue of the JOURNAL is an example of a short-cut method which should appeal to all who have occasion to determine the characteristics of direct-current circuits. An article by Mr. Carle describing a method of securing the same results was published in another periodical some time ago, in which a number of charts, laid out with rectangular co-ordinates with equal divisions, were shown. As the lines representing distance and size of wire radiated from a common center, the range was limited, it being necessary to use a number of charts to include all common sizes of wire and ordinary lengths of circuits, and the accuracy was variable, depending upon the slant of the radiating lines. Also the lines defining the Underwriter's limits were curved lines.

By laying out the chart with logarithmic scales, it was found that

the information contained in the several charts required by the first method could be obtained from one chart and at the same time the variations in accuracy due to slanting lines was eliminated, as all the lines become parallel and the Underwriter's limit lines straight. This chart has a range as great as is desirable and is so plain and self-evident that results can be quickly and accurately determined.

A. H. McIntire

The A. I. E. E. Report

The annual report of the Board of Directors of the American Institute of Electrical Engineers shows a prosperous condition.

The accessions to membership last year, 1 361, exceeded the total membership at the end of seventeen years. The aggregate is now 5 674. This number does not include nearly 1 000 who are enrolled as students, and who constitute a most energetic and loyal element of the organization. There are now 48 local organizations, of which 15 have been formed during the year—a gain of nearly 50 percent. The transactions for 1907 cover about 1 850 pages and will be issued in two volumes. The receipts per member exceed the disbursements per member by $1.28, which is a trifle more than the average for the past six years.

The exacting requirements for full membership are shown by the fact that only 43, or approximately one percent of the associate members, were transferred to full membership during the year.

The question presenting itself to the profession of electrical engineers—and particularly to the younger ones—is not, Why should I join the Institute? but it is, Can I afford not to belong to the American Institute of Electrical Engineers?

Chas. F. Scott

STEAM TURBINES

J. N. BAILEY

Turbine Department, British Westinghouse Electric & Manufacturing Company

STEAM turbines may be classified as follows:—

De Laval—In the ideal De Laval turbine the steam is completely expanded adiabitically in the nozzles, thus acquiring a high velocity at the expense of its heat energy and gives up the whole of its kinetic energy to the moving blades. If the velocity of the steam at the mouth of the nozzle is V, the velocity of the buckets in the ideal case should be $V/2$, whence the velocity on leaving the buckets is zero, if the direction of the steam is completely reversed. (See Fig. 1.)

Parsons—The Parsons turbine is of the combined impulse and reaction type. The steam does part of the work by impulse and part by the reaction due to the acceleration of the steam in the blades. These are of a form similar to simple converging nozzles in which the steam is expanded. The expansion of the steam is, therefore, partly completed in the stationary or guide blades and partly in the moving blades. The fixed blades direct the steam at the proper angle to cause it to enter the moving blades without shock. (See Fig. 2.)

Zolley or Rateau—The Zolley or Rateau turbines are developments of the De Laval and consist of a number of De Laval elements in series, each succeeding section utilizing the exhaust steam from the preceding element as in a multiple expansion reciprocating engine. The steam is partly expanded in the first row of nozzles, strikes the first row of buckets and leaves them with practically zero velocity. It is then further expanded through the second row of nozzles, strikes a second row of moving buckets and again leaves them with zero velocity. This process is repeated until the steam is completely expanded. (See Fig. 3.)

Curtis—The Curtis turbine lowers the bucket velocity required by fractional velocity reduction, each element consisting of at least two rows of moving and one row of stationary blades. The steam leaving the nozzle impinges upon the blades, gives up a fraction of its energy to the first row of moving blades; passes through the fixed blades without change of velocity and then passes through the second row of moving blades in which the remaining kinetic energy is extracted. This, of course, applies only to the two bucket wheels,

the energy being extracted in three stages in a three bucket wheel. A further reduction of blade velocity is secured by combining the velocity and pressure stage principles. That is, after passing the steam through the first set of moving and stationary blades it may be further expanded in a second or in multiple stages. (See Fig. 4.)

An analogy may be drawn between the action of steam flowing through a turbine and a perfectly elastic ball falling through a height onto vanes moving at one-half the velocity of the ball at the moment of impact. Figs. 1 to 4 illustrate this analogy, the ball's weight w representing the steam flowing per second, V its velocity

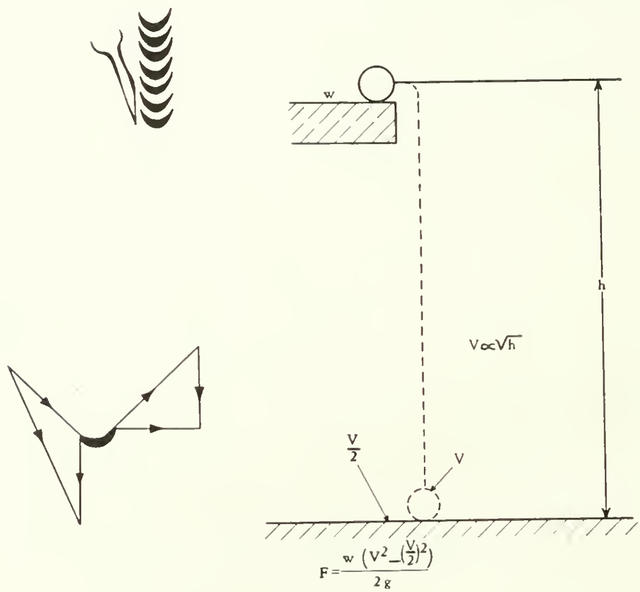


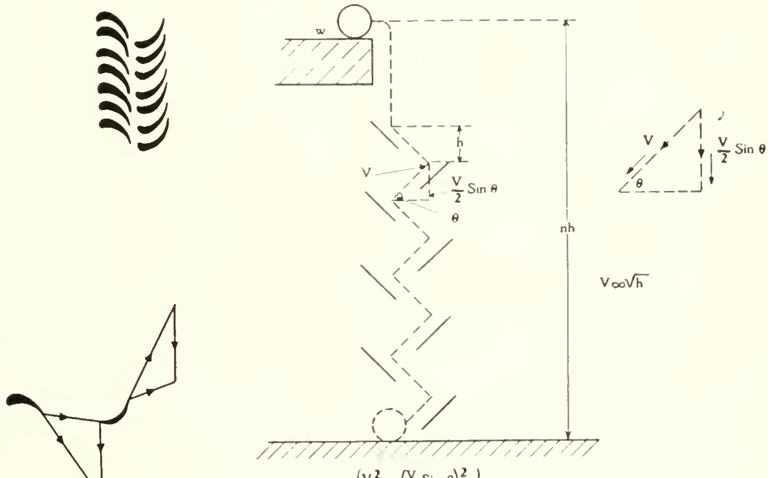
FIG. 1

and h the head in feet. In each of these cases $V = \sqrt{2gh}$ in which h represents the height of the fall or the available energy in the case of steam, hence V varies as the square root of the available energy.

When steam is expanded in a suitably formed nozzle its theoretical velocity will be,

$V = 224 \sqrt{H_1 - \{H_2\,x + q\,(1 - x)\}}$ or $V = 224 \sqrt{\text{B.t.u.}}$ ft. pr. sec.
Where H_1 = total heat at P_1, H_2 = total heat at P_2, x = dryness fraction, q = heat of liquid. Thus, if the available energy is 325 B.t.u., the velocity will be 4 040 feet per second. It is apparent

from this that the velocities are of a very high order, especially where the available heat energy is large. The difficulties encountered with high velocities are two-fold:—1—Erosion of the blades; 2—Large friction losses. It is now well known that steam carrying moisture along with it at a high velocity is capable of a cutting action not unlike that of a sand blast; in fact, that even the hardest steel may be eroded more or less in this way. Buckets may have highly polished surfaces and sharp edges offering little resistance to the entrance of the steam, but in time they will lose their sharp edges due to the cutting action under the above conditions and each blade will then present a more or less flat surface which deflects the



$$F = \frac{nw\left\{V^2 - \left(\frac{V}{2}\sin\theta\right)^2\right\}}{2g}$$

FIG. 2

steam, causes eddies and reduces the economy. A phenomenon now well known is that there is a certain limiting critical velocity below which the cutting action of steam ceases regardless of the period of duration. It is because of this fact that erosion in the Parson's turbine is avoided and its high economy maintained indefinitely.

There are certain considerations in the theory of steam turbines which indicate the directions in which the effort of designers should be directed to secure the highest efficiency with a maximum durability, simplicity and low cost of construction. A few of these aims and the possible points of attack may be summed up in the following:—

1—Reduced steam consumption,

2—Increased peripheral speed,

3—Simplicity of design with minimum number of moving parts.

From a practical standpoint the following points may be considered:

1—Accuracy of workmanship,

2—Mechanical designs arranged so that expansion and contraction under all conditions of load and steam pressure are provided for in such a manner as to not interfere with safe operation.

These points will be considered in the order given:—

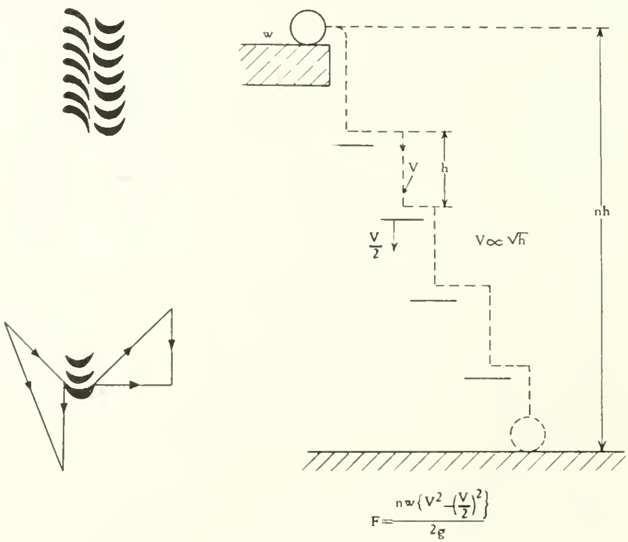


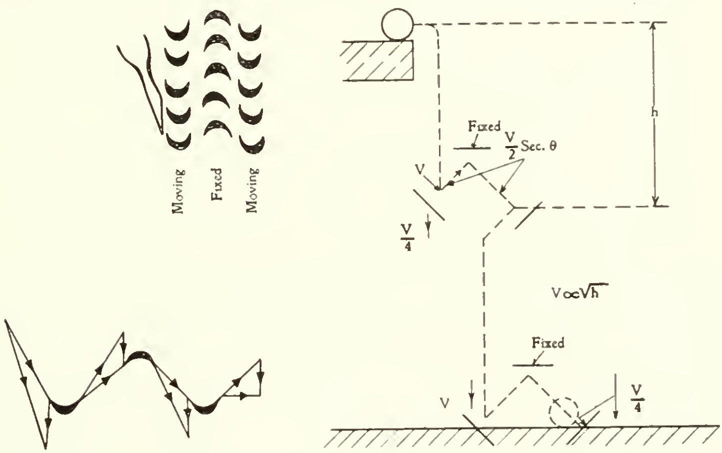
FIG. 3

REDUCED STEAM CONSUMPTION

The theoretical available heat energy in steam between pressure P_1 and P_2 may be obtained from an entropy chart or from one of the many formulas found in text books and engineering papers. One of these by Macfarlane Grey will be found convenient, $\left(\frac{1438 \times 0.7\, T_1}{T_1} + \frac{T_1 - T_2}{T_1 + T_2}\right) T_1 - T_2$ this being a slight modification of Clausius' formula. Any heat engine or turbine which converted all the available energy in steam as given by the above formula into useful work would have an efficiency of 100 percent. In practice, however, the efficiency ratio (better known as the Rankin cycle or Willans' efficiency) varies from 55 up to slightly over

70 percent in exceptional cases. Thus nearly one-half of the available heat is rejected by the turbine.

A pound of steam at any pressure, if allowed to expand to some lower pressure without doing work, will become superheated, as the total heat remains unaffected. If it is allowed to expand and to do work, the superheat may diminish or disappear altogether; or further, it may pass the saturation point and a portion of the steam be condensed. The temperature range or the amount of adiabatic condensation may roughly be considered as a measure of the work done. This is a very important view point, yet is probably the least understood and most neglected consideration in turbine design. The



$$F = \frac{2\left[w\left\{V^2 - \left(\frac{V}{4}\right)^2\right\} + w\left\{\left(\frac{V}{2}\right)^2 - \left(\frac{V}{4}\right)^2\right\}\right]}{2g}$$

FIG. 4

water that separates out is not that due to condensation by leakage of heat across the cylinder walls. It is due to the abstraction of heat in the form of work which lowers the temperature below the saturation point. The popular idea throughout the whole era of reciprocating steam engine practice has been to avoid water in the cylinders. Yet no successful steam engine of any kind, unless dealing with very highly superheated steam, can work without water separating out in the cylinders. It has also been the popular idea to imagine the reciprocating steam engine as purely a pressure engine, like an hydraulic motor, but it is nothing of the sort. It is a heat engine. As heat is hypothetically interchangeable with work, it takes a considerable amount of heat energy to convert water into

steam; conversely, the extraction of work from steam should convert at least a portion of it back again into water.

If steam is taken at the pressure P_1 and in doing work is expanded to the pressure P_2, the following relations between the various heat factors exists:—

$$H_1 - H_2 = \overbrace{H_1 - \{H_2 x + q(1-x)\}}^{A} - [H_1 - \{H_2 x + q(1-x)\} - \overbrace{r(1-x)}^{B}]$$

Where q = heat of the liquid, x = wetness fraction, r = heat of vaporization, H_1 and H_2 = total heat in the steam at pressure P_1 and P_2 respectively. The part of the expression A represents the

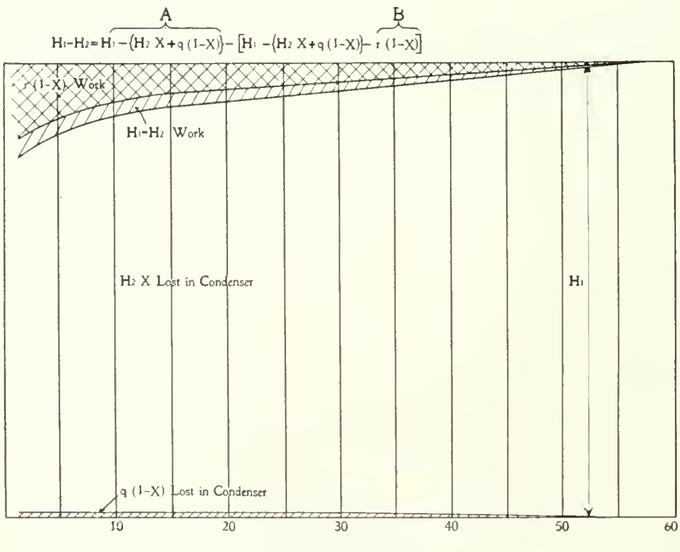


FIG. 5—DIAGRAM OF HEAT VALUES

maximum energy available between P_1 and P_2 and the part B represents the energy given up in work by the liquefaction of $(1-x)$ amount of steam. H_1-H_2 is the true gas value of the steam expressed in B.t.u.'s.

Any of the quantities which can be obtained by the foregoing equation can be obtained more easily from an entropy chart than from the formula, but the expression shows analytically what the entropy chart shows in the concrete. In Fig. 5 the relative values of the portions of the total heat in the steam used in work and those rejected or lost in the condenser from 60 pounds absolute pres-

sure to condenser pressure are clearly shown. The portions H_1-H_2 and r (1-x) and the very much larger $H_2 x$ and q (1-x) merely warm the circulating water delivered to the condenser and are therefore lost. These values H_1-H_2 and r (1-x) represent the maximum theoretical values. As a matter of fact a common and useful figure in actual practice is 60 percent of these. This is one of the openings for attack by the young and courageous engineer, and let him bear in mind that the more water he gets in his turbine the better, but it must be water due to the conversion of latent heat into work. Water due to condensation by radiation of heat through the cylinder walls is not only useless but exceedingly harmful. In Fig. 5 it may be seen how rapid is the surrender of heat towards zero pressure, showing how advantageous a high vacuum is to a turbine. A reciprocating engine would require an absurdly large low pressure cylinder to avail itself of so low a pressure and consequently so large a volume. For this reason the turbine is able to enter a field from which the reciprocating engine is debarred.

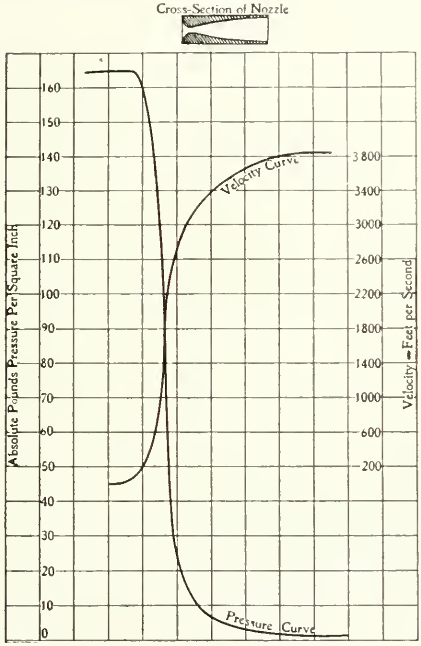


FIG. 6—PRESSURE AND VELOCITY CURVES (THURSTON)

Diam. of throat 0.4, velocity of efflux 3810 ft. per sec., expanding from 150 lbs. per sq. in. to 26 in. vacuum, lbs. steam per hour 982, theoretical horse-power 111.5.

It has been shown how desirable it is to get steam turned into water from a standpoint of economy. It will also be shown how harmful water in the cylinder is from another point of view. Since the moisture due to the expansion of steam is capable of giving up but little heat energy by a further reduction of pressure, the energy rquired to accelerate it after impinging upon the moving blade must be supplied by that portion of the mixture which is still steam. While it is bad to have water in the cylinder, it is impossible to have

efficiency without it, owing to the natural laws governing the extraction of work from steam.

An argument which has frequently been brought forward is that, owing to the constantly increasing moisture in the steam due to the expansion in previous stages, the low pressure stages of the turbine have a lower efficiency owing to the great increase in friction caused by the entrained moisture. However, this argument has little weight for the reason that although the area over which the steam passes is much greater in the low pressure than in the high pressure end of the turbine, and although the velocity of the steam is greater at the low pressure end, it must be remembered that the frictional loss of steam at any given velocity is directly proportional to its density. It is a fact, however, that the density of the steam in the lower expansions decreases far more rapidly than the blade surface and the cube of the steam velocity increase and hence the efficiency of the low pressure stages of the turbine is greater than that of the high pressure portion. This higher efficiency is also partly due to the fact that the proportion of steam lost by leakage in the later stages is insignificant although considerable in the earlier stages.

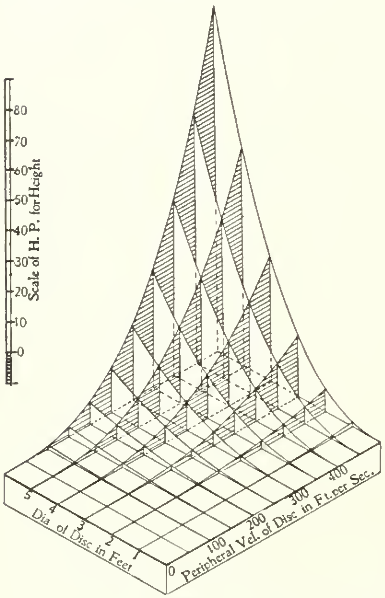


FIG. 7—CURVE SHOWING RELATION BETWEEN DIAMETER OF DISC, VELOCITY AND HORSE-POWER ABSORBED IN FRICTION WITH A STEAM PRESSURE OF 60 LBS. ABSOLUTE

INCREASED PERIPHERAL SPEED

Can higher peripheral velocities be used, and if so, what benefit may be derived? If a body such as steam possess kinetic energy, it is found that maximum efficiency is attained by allowing the steam to strike the blades as in a De Laval turbine where the speed of the wheel is half that of the steam, and where the steam, after leaving the wheel, is prevented from again coming into contact with the

wheel. The blades must also be so narrow that a minimum surface is exposed for the steam to travel over, yet be broad enough to give easy entrance and exit angles and so avoid shock. As the steam in a De Laval turbine expands in a single stage from boiler pressure down to condenser pressure the velocity of the steam is enormous, approximating 4 000 feet per second. The wheel should therefore have a peripheral velocity of 2 000 feet per second to be theoretically correct. Practically, this is a speed involving stresses beyond the physical characteristics of any known material. It is, therefore, necessary to reduce the peripheral velocity and consequently impair the efficiency.

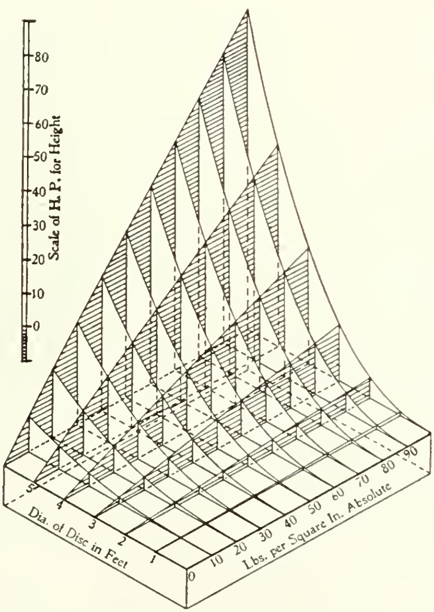


FIG. 8—CURVE SHOWING RELATION BETWEEN DIAMETER, STEAM PRESSURE, ABSOLUTE, AND HORSE-POWER ABSORBED IN FRICTION WITH DISCS REVOLVING AT 400 FEET PER SECOND, PERIPHERAL VELOCITY

The pressure drop and velocity curves of steam as it expands from boiler pressure to condenser pressure in a nozzle suitably formed to give maximum velocity and efficiency are given in Fig. 6. But even with the velocities made possible by the highest grade nickel steel and the disc thickened towards the center as in the well-known De Laval wheel, it is impossible to prevent the other losses from being considerable. The greatest of these is skin friction between the steam and the sides of the wheel. As in the case of the desire to obtain the greatest wetness fraction of the steam, there is the contrary desire for other reasons to keep the wetness fraction down and maintain the steam as dry as possible, so it is found that the desire to use as high blade velocity as possible brings in its train a multitude of reasons why it should not be done. This will best be seen by referring to Figs. 7 and 8 showing curves plot-

ted from Prof. Stodola's formula for skin friction for rotating discs. This formula is as follows*:—

$$N = 0.02295 \frac{A\ D^{2.5}\ U^3\ Y}{100}$$

Where:—N = horsepower to drive disc, A = constant = 3.14, U = peripheral velocity in feet per second, Y = specific weight of surrounding medium in lbs. per cubic foot, D = diameter of disc in feet.

It is obvious that the skin friction between the steam striking the blades or buckets must be greater even than at the periphery of the disc itself, as after all, it is simply a case of fluid friction and the rate of increase of friction with velocity. This then applies to all types of steam turbines; a low velocity means a large surface and a high velocity a small surface, both resulting in loss of efficiency. Nevertheless, turbines having high blade velocities are more economical than those with low, and this is especially the case with turbines of moderate speed. The curves show how important it is to reduce idle surface at the periphery of the wheel as the friction increases as a high power of the diameter, yet there is a type of turbine which has a channel blade shroud which may be considered as representing strips from the periphery of discs, two to each row of blades. It can readily be seen that the friction losses must be very great indeed, especially as the wettest steam will be thrown out to the cylinder walls.

In addition to the skin friction of the flanges, the portion of the channel to which the blades are riveted is also subject to frictional resistance. The object for which the channel shrouding was designed is to prevent the leakage of steam past the ends of the blades, but it is evident for mechanical reasons that it is not possible to run the shrouded blades with smaller clearances than are employed with unprotected blades. The very object for which this shrouding is intended is, therefore, defeated, as the steam which is lost by leakage is entirely useless where channel shrouding is employed, whereas with naked blades the leakage steam is partly directed by the working steam and thus gives up a portion of its energy to the moving blades. Of course, aside from the question of

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*This formula should be used with a considerable degree of reserve as experiments on actual machines do not agree well with the results obtained by its use. The curves do, however, show the general law of variation. There are reasons to believe that the exponent 2.5 and the value of A are not constants but may vary considerably.

leakage, the principal object for which the channel shrouding was designed is to prevent blade stripping, it being intended that should accidental rubbing occur, the channel shrouding and flanges would be worn away without serious damage to the blading. Unfortunately, however, experience has shown that comparatively little wear is ever discovered on the flanges of the shrouding after contact has occurred, the flanges in every instance being turned over or spun down to a mushroom shape, thus increasing the contact surface in either case. It is almost unnecessary to point out that considerable heat is generated when surfaces having a velocity of several hundred feet per second come into contact with each other.

SIMPLICITY OF DESIGN WITH MINIMUM NUMBER OF MOVING PARTS

This item, perhaps, more than any other, indicates the most promising road to improvement of turbine design, and it affects the

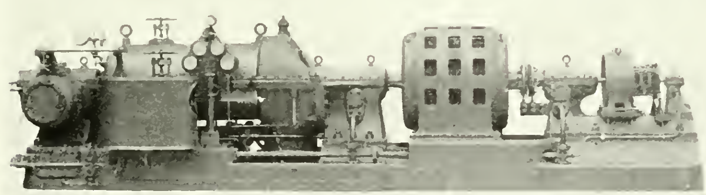


FIG. 9—BRITISH WESTINGHOUSE-PARSONS TURBINE, GENERATOR AND EXCITER

ultimate issue in two very different and important ways. In the first place, the simpler the design, the less chance there is of anything going wrong with the running of the plant, and if only the idle surface can be kept down to a minimum and every advantage taken to secure correct steam and blade velocities, the turbine is bound to be economical. In the second place, simplicity of design helps to reduce the manufacturing costs and the machine competes more advantageously in the market than can a complicated and expensive machine. Manufacturers are gradually developing along these lines and improvements are being made and adopted which prove in daily service the wisdom of departing from what were formerly considered indispensable means of arriving at the same result.

ACCURACY OF WORKMANSHIP

As in all high grade machinery, the machine work on steam turbines must be of the best quality to insure successful and eco-

nomical operation. The necessity for true work, circular bores and perfect alignment need hardly be commented upon. Such parts as bearings, for instance, must be true to size, circular and have a high finish; link gear must be perfectly free, yet fit well and have practically no lost motion. Blades cannot be too smooth to insure as small a friction loss as possible, as is clearly shown in the diagrams of Stodola's experiment in Figs. 7 and 8. The curvature of the blades should be such that the steam enters them without shock and without eddies.

LOW PRESSURE TURBINES

A paper on turbines would be very incomplete if mention of the exhaust steam turbine and the wide field for its development were neglected. Collieries, rolling mills and other industries that have exhaust steam to spare are contemplating the installation of exhaust steam turbine plants by means of which large sums of money may be saved. A large amount of heat energy is available in steam when expanded from atmospheric to condenser pressure, as has been previously shown. As much as 70 percent of this available energy can be saved and turned into useful work by means of the exhaust turbine. A low pressure steam turbine differs only from a high pressure steam turbine in the decreased number of its stages; but there is only about one-half the available energy to be extracted that there is in a high pressure turbine. As low pressure exhaust steam is not always available, in certain industries, it is necessary at times to operate a low pressure turbine with high pressure steam. To meet this condition of operation with the maximum efficiency under all conditions a combined type of impulse and reaction turbine has been developed in which the high pressure steam is first expanded in nozzles and its energy partly extracted in the impulse element, after which it passes to the low pressure or exhaust steam portion of the turbine. Normally, however, when an ample supply of low pressure steam is available, the high pressure impulse element is not used. The particular advantage of the impulse element for this service is that it adds practically nothing to the length of the turbine and but little to its weight.

Such a combined turbine is controlled by means of a governor which maintains the speed constant by throttling the inlet steam. It is so arranged, however, that when the supply of exhaust steam is shut off or insufficient to carry the load, the governor opens the high pressure by-pass valve which admits high pressure steam to the

nozzles of the impulse element. It will be evident, therefore, that whether operating on high or low pressure steam, the conditions of operation are always such as to obtain maximum efficiency. In some cases the supply of exhaust steam is entirely intermittent or periodical and of a larger quantity than required at any time. In order to prevent having to exhaust the surplus steam into the atmosphere and lose its heat, a heat accumulator, invented by Prof. Rateau, is used for storing the surplus heat in the steam until the supply of exhaust steam is cut off. The pressure in the accumulator then decreases and since the water is then hotter than that corresponding to the pressure of the vapor it evaporates and thus gives up the heat stored in it during the period of action. Water possesses a higher specific heat than any substance, with the exception of hydrogen, so that it is a most convenient and excellent substance to use to absorb the surplus heat.

A turbine set of this type is shown in Fig. 9. There are two steam chests of similar design, the smaller taking the high pressure steam and the larger the exhaust steam. The control mechanism is so arranged that the low pressure governor valve always leads the high pressure. An arrangement is also provided whereby the low pressure safety governor valve is utilized to close the passage for low pressure steam automatically in the event of its being cut off at its source. This prevents any danger from the vacuum in the turbine coming back into the exhaust main on small loads.

BRITISH, AMERICAN AND GERMAN STANDARDS FOR ELECTRICAL APPARATUS

J. S. PECK

THE Engineering Standards Committee of Great Britain has recently issued a "Report on British Standards for Electrical Machinery." This report appears very incomplete when compared with the standardization rules of the American Institute of Electrical Engineers and with those published by the German Technical Society, but it is really of a preliminary nature and will undoubtedly be made more complete in the near future; in fact, tests are now being carried out at the National Physical Laboratory in London for the purpose of obtaining information regarding the effect of long time application of high voltages to insulating materials, in order to guide the Committee in determining the proper insulation tests to be applied to electrical machinery.

A comparison of the standard rules issued in Great Britain, Germany and America is of considerable interest as showing the views of engineers in the different countries as to safe operating conditions. The temperatures, overloads and testing voltages called for in the standard specifications of the three different countries are given in Tables I, II and III. The indicated temperature instead of

TABLE I—MAXIMUM OPERATING TEMPERATURES OF ELECTRICAL APPARATUS.

AS SPECIFIED BY THE ENGINEERING STANDARDS COMMITTEE OF GREAT BRITAIN, THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS AND THE VERBAND DEUTSCHER ELECTROTECHNIKER.

Part of Machine	American		British		German					
					Cotton		Paper		Mica	
	T*	R†	T*	R†	T*	R†	T*	R†	T*	R†
Windings-stationary	75	75	.....	85	......	95	....	105	....	125
" moving	75	75	75	85	85	......	95	......	115	......
Commutators & brushes	80	....	.....	.....	......	......	....	......	95	......
Collector rings	90	....	.....	.....	85	......	95	......	115	......
Bearings	65	....	.....	.....	......	......	....	......	....	......
Squirrel cage rotors	80	....	.....	.....	85+	......	105+	......	125+	......
Transformers	75	75	75	75	95	......	105	......	125	......
Railway Motors:										
Continuous rating	100	125	.....	.....		......	....	......	....	......
One hour rating	....	....	.....	.....	105	105	115	115	135	135

To obtain temperature rises, subtract 25 degrees from American and British temperature and 35 degrees from German temperature. T* stands for thermometer readings, R † for increase in resistance readings. All temperatures in degrees C.

the rise in temperature is given, as this is really the value which determines th rate of deterioration of the machine. In America and Great Britain, the temperature rise is given above a room temperature of 25 degrees C., while in Germany a room temperature of 35 degrees is permitted. This in itself adds ten degrees to the allowable working temperature under German conditions.

TABLE II—OVERLOAD REQUIREMENTS

	American	German
Generators	25 percent for 2 hrs.	25 percent for ½ hr.
Motors	25 " " 2 "	25 " " ½ hr.
	50 " " 1 min.	40 " " 3 min.
Rotary Converters	25 " " 2 hrs.	25 " " 30 mins.
	50 " " 30 mins.	40 " " 3 mins.
Transformers	25 " " 2 hrs.	40 " " 3 mins.

In the German rules, different temperature rises are permitted for different classes of insulation. Cotton insulation demands the lowest temperature, paper insulation comes next, with about ten degrees higher rise, while mica, asbestos and similar insulating material is permitted a temperature about thirty degrees higher than is allowed for cotton insulation. In the British and American Standards it is stated that where special heat resisting insulating material is used, higher temperatures may be allowed than with the ordinary

TABLE III—INSULATION TESTS

	American	German
Minimum testing voltage	1 000 for one min.	100 for 30 minutes
Apparatus for voltages between 5 000 and 10 000	Double for one min.	Normal + 5 000 for 30 minutes
Apparatus for voltages over 10 000	Double for one min.	Normal + 50 percent for 30 minutes

insulating material, but no limits are given. This distinction in permissible temperature rise for machines insulated with different kinds of material seems a step in the right direction, for there is no reason why a machine insulated with asbestos and mica throughout should be operated at as low a temperature as a machine insulated with cotton and similar perishable material. The great danger in this classification appears to be in the opportunity it offers for fraud, on

account of the inability of the customer to determine whether all of the insulation in a machine is really of a fireproof nature or not. Everyone familiar with the insulation of electrical apparatus knows that many of the so-called fireproof insulating materials are anything but fireproof, and while it is not likely that responsible manufacturing companies who have had wide experience with different classes of insulating materials will put out apparatus which will not give a reasonable life, there is the possibility that manufacturing companies with less experience may be tempted to operate at higher temperatures than the insulating materials will stand. It is not probable that any conservative British or American engineer would ever accept electrical apparatus operating at a temperature of 125 degrees regardless of the class of insulation employed, and it is doubtful whether many Germany engineers would accept such machines. Nevertheless, this temperature is permitted by the German rules with certain classes of insulating material.

In general it may be stated that the American standards are much more conservative than the German, while the British standards come somewhere between the two, but are nearer to the American than to the German. In Europe, the keenness of the competition in the sale of electrical machinery has made it necessary for manufacturers to take advantage of every possible means for reducing the cost of their apparatus. Increasing the temperature limit, which is equivalent to decreasing the cost per kilowatt, is one of the easiest methods of increasing output. To secure safe working at higher temperature, the German manufacturers have been studying the use of non-combustible materials. This study has also been carried on extensively in America, but American manufacturers have shown a tendency to retain the low temperature limits, thus giving their customers the benefit of the improved insulation, in that they obtain machinery having longer life and greater immunity from breakdown.

British and American electrical manufacturing companies know how difficult it is to compete in price with the German manufacturers. Perhaps the more liberal standards under which the Germans work are in part responsible for this, in any event the tables here given will repay careful study on the part of British and American engineers.

GRAPHICAL DETERMINATION OF VOLTAGE DROP IN DIRECT-CURRENT FEEDERS

R. W. STOVEL and N. A. CARLE

THE determination of the voltage loss in transmission is one of the simplest yet most frequent operations in the designing of direct-current distributions of light and power.

The formula is $C = \frac{E}{R}$ . . . . (1)

where C = current in amperes, E = loss in volts and R = resistance in ohms.

The resistance is that of the entire circuit and varies with the length of the circuit, area of cross-section and the specific resistance of the material of the circuit. Copper wire only is considered in the graphical solution offered in this article. The basis of specific resistance is that of a piece of copper wire one foot in length and 0.001 inch in diameter. This is called a mil-foot and its resistance varies with the purity of the copper and its temperature. For copper having a conductivity equal to Matthiesson's Standard, and at 0 degree C. the resistance is 9.59 ohms per mil-foot. Correcting this for 98 percent conductivity and 75 degrees F., the resistance is 10.7 ohms per mil-foot. This represents the average commercial conditions. The resistance formula is, $R = \frac{K \times L}{\text{c. m.}}$ . . . . (2)

where R = resistance in ohms, K = specific resistance of copper wire, L = entire length of circuit in feet and c. m. = area of cross-section of wire in circular mils = $\overline{\text{diameter in inches}}^2$.

Combining equations (1) and (2) and substituting the specific resistance of one mil-foot of copper wire of 98 percent conductivity and 75 degrees F., the formula becomes, $C = \frac{E \times \text{c.m.}}{10.7 \times L}$. Rearranging the terms $E = \frac{10.7 \times C \times L}{\text{c.m.}}$. This is usually expressed as

$$\text{volts lost} = \frac{10.7 \times \text{amperes} \times \text{length of circuit in feet}}{\text{circular mils}}$$

Various devices in different forms have been developed to facilitate rapidity in calculations of this sort, but the diagram given herewith is put forward in the belief that it has some distinctive merits of its own. The relations between any three varying factors can be shown graphically on a sheet of cross-section paper by using one

quadrant of rectangular co-ordinates. By the use of two quadrants the relations between four varying factors may be shown. The above formula contains four variables and hence two quadrants are necessary in making up a diagram of this formula. If the diagram is designed using the ordinary scales of equal divisions, the lines showing the factors not represented by the axes are in general lines or curves radiating from a common point and as such have a limited range for a given accuracy and also a varying percentage of accuracy throughout their range.

If, however, scales proportional to the logarithms of the variable factors are used, the lines which before radiated will be parallel straight lines with a greatly increased range in the same space and have an equal percentage of accuracy at all points of the range. Although logarithms are used in the preparation of this chart, giving a foreshortened scale for the horizontal axes, this need not present any complications to those unacquainted with the use of logarithms, as the spaces between the marked lines may be interpolated in the regular manner with sufficient accuracy.

The diagram is capable of being read with sufficient accuracy for all practical problems and is of sufficient range to include all ordinary work. In determining drop in conductors, it should be remembered that great accuracy is labor lost, as the current is seldom known within ten percent of an exact value and the temperature is seldom considered, although a difference of 45 degrees F. causes a ten percent variation in resistance. Furthermore, it is necessary to choose between commercial sizes of wire which vary by more than ten percent.

A diagram or chart gives a better understanding of a formula than a device with revolving scale on account of the greater accuracy and less chance of mis-reading or mis-setting the scales. Another advantage of a graphical method is that not only is the result of a particular problem determined, but the result of a variation in any of the factors is evident, and a better sense of relative proportions is obtained.

The diagram is designed to read directly the volts loss for different amounts of current transmitted over various sizes of wires of different lengths. The carrying capacity allowed by the National Electrical Code for weather-proof insulated wires for open work and for rubber covered wires for concealed work are indicated on the diagram by lines cutting across the lines representing the wire sizes.

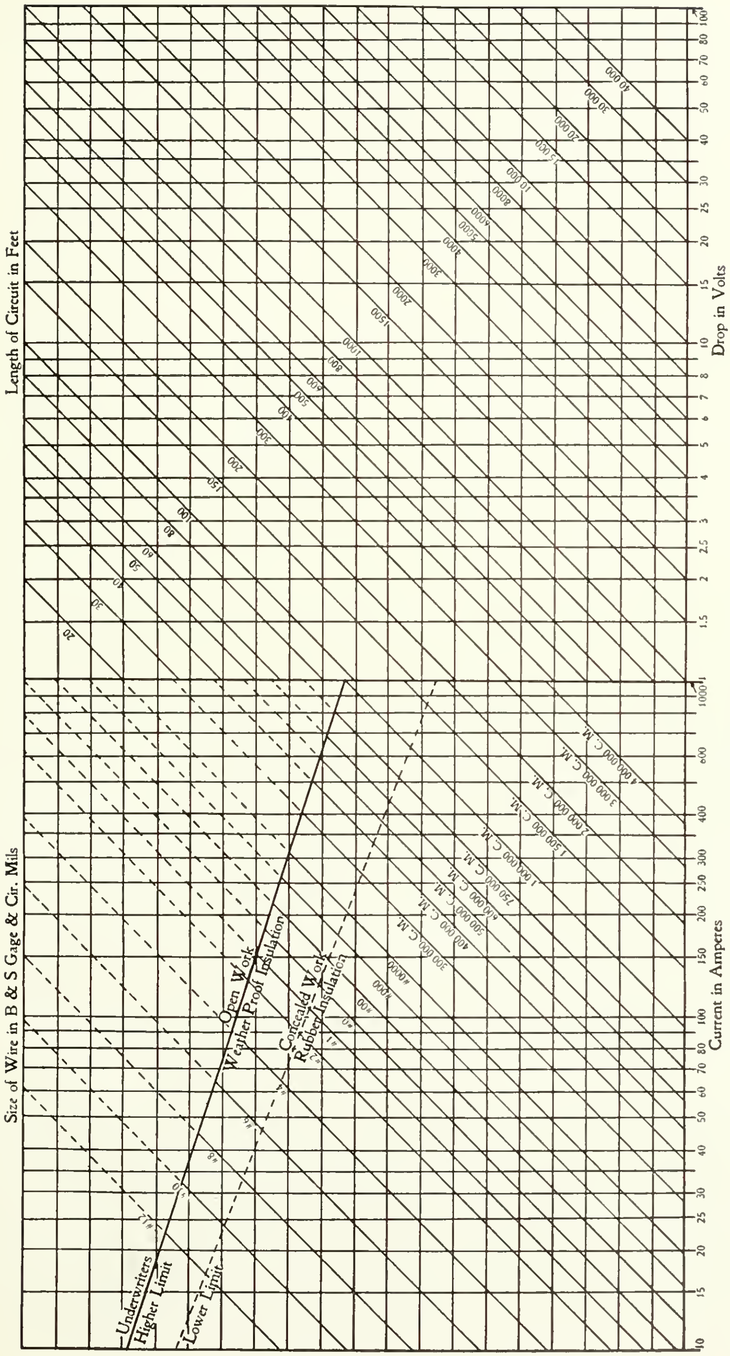


CHART FOR USE IN FIGURING WIRING FOR DIRECT-CURRENT CIRCUITS
75° F — 98 % conductivity.

Above the higher limit representing weather-proof insulation wires for open work, the wire sizes are dotted to indicate that the carrying capacity allowed by the code has been exceeded.

EXAMPLE I

How many volts would be lost in transmitting 300 amperes over a circuit 5 000 feet long, using a 400 000 circular mil cable?

Starting with *300 Amperes*, read up to *400 000 c. m. Size of Wire*, then across to *5 000 feet Total Length of Circuit* and down to *Drop in volts* of *40*, which is the desired result.

What is the smallest size of wire allowed by the Code for the above service and what will be the drop in volts?

Starting with *300 Amperes*, read up to the intersection of this vertical line and the *Underwriters' Higher Limit* for open work using weather proof insulation. The largest size of wire shown within this limit is *No. 0 000*. Read across from the intersection of the vertical line through *300 Amperes*, and the line marked *No. 0 000 Size of Wire* to *5 000 feet Total Length of Circuit* and down to the *Drop in Volts* and the answer will be found to be approximately 75 volts lost.

EXAMPLE II

How many volts will be lost in transmitting 50 amperes on open wiring with weather-proof insulation for a distance of 100 feet, using the smallest size of wire allowed by the National Electrical Code?

The total length of circuit will be 200 feet. Starting with *50 Amperes*, read up to *No. 6 Size of Wire*, which is the largest within the *Underwriters' Higher Limits*, then across to *200 feet Length of Circuit*, and then down to approximately *4.1 Drop in Volts*.

If this had been concealed wiring a No. 4 wire would have been required according to the Underwriters' limitation. This would give a drop of 2.5 volts.

EXAMPLE III

What would be the proper size of wire for open work, using weather proof insulation, and the amount of current carried for a ten volt loss on a circuit of 600 feet total length?

Starting with *Drop in Volts* of *10*, read up to *600 feet Total Length of Circuit*, then over to *No. 000 Size of Wire* which comes within the Underwriters' limit and then down to approximately *260*

Amperes. With rubber insulation and concealed work a No. 4 wire will be as large as could be used for the same drop and it would have a carrying capacity of only 65 amperes.

EXAMPLE IV

What distance can 80 amperes be carried, with eight volts drop, in accordance with the National Electrical Code, using weather-proof insulation on open work?

Starting with *80 Amperes* read up to *No. 4 Wire*, which is within the *Underwriters' Higher Limit*, then extend a line horizontally from this point to the right until it intersects the vertical line representing a *Drop in Volts* of *8*. The intersection falls between the lines representing *300* and *400* feet *Length of Circuit*. The location of this point is approximately nine-tenths of the space between the 300 and 400 feet lines, so that 390 feet can be taken as the approximate length of circuit to give eight volts drop.

EXAMPLE V

Would the rules of the National Electrical Code permit the use of a No. 00 wire for carrying 200 amperes and what would be the drop in voltage on a circuit 1 000 feet in length?

Starting with *200 Amperes* read up to No. 00 *Size of Wire*. This intersection occurs between the limits for open and concealed work, therefore this size of wire is allowable for open work, but for concealed work a No. 0 000 wire would have to be used. For open work read across to the right from the intersection of the vertical line through *200 Amperes* and *No. 00 Wire* to *1 000 feet Length of Circuit*, and then down vertically to the base line where a drop of approximately *16 Volts* is indicated.

For concealed work, read across to the right from the intersection of a vertical line through *200 Amperes* and *No. 0 000 Wire* to *1 000 feet Length of Circuit* and then down vertically where the drop will be found to be approximately ten volts.

CIRCUIT-INTERRUPTING DEVICES—VI (Cont.)

OIL CIRCUIT BREAKERS—DETAIL FEATURES

H. G. MacDONALD

IN every device, no matter of what description or for what purpose it is designed, there are certain parts which are absolutely essential and without which the apparatus cannot exist or perform the function for which it was intended. In a circuit breaker these parts are:—the contacts or current-carrying parts through which the circuit is made and broken; the insulation separating contact parts of different potentials from each other and from ground, and the operating mechanism by means of which the contacts are opened and closed. These essential parts have been named in the order of their relative importance, though, as the higher voltages met with in oil circuit breaker practice are considered, the relative positions of the first two are undoubtedly reversed. They will be considered, however, in the order given.

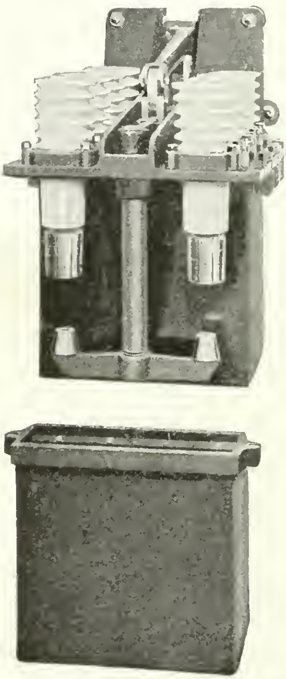


FIG. 6—CONICAL TYPE OF CONTACT

Used with slight modifications on both large and small capacity oil circuit breakers.

CONTACTS

The contacts are the parts which carry the current and which, when separated by the action of the mechanism, open the circuit. They must be of ample cross-section to carry the current for which the circuit breaker is designed without undue rise in temperature. The permissible temperature rise varies with different kinds of service. For example, the National Board of Fire Underwriters places a limit on the temperatures allowable on a circuit breaker to be used on a switchboard far below that allowable if the circuit breaker is to be used for railway service. Individual manufacturers also have different ideas as to what current density per unit area of cross-section and of contact surface is within the limit of good practice.

In addition to the current-carrying parts being of ample cross-section the area of the contact surfaces must be sufficient to carry safely the required current. It is often possible to increase the capacity of the contact surfaces of a circuit breaker by increasing the pressure with which these surfaces are held in contact.* The design of the contacts must be such that the carrying capacity of the contact surfaces will not be impaired by the arcing likely to occur between these faces when opening the circuit. This may be accomplished either by the use of auxiliary contacts which remain closed until the main current carrying surfaces have separated and which take the arc due to the final opening of the circuit, or by making the contacts of a form similar to that of controller fingers where the main contact surfaces open first and the final break occurs on the points of the fingers. These two types of contacts are illustrated by Figs. 6 and 7 respectively.

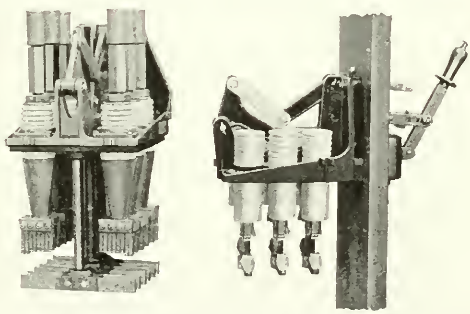


FIG. 7—VARIATIONS OF FINGER TYPE CONTACT

Showing two forms of oil circuit breakers for large and medium capacity service respectively.

Another essential of a good contact is that it shall not be easily thrown out of adjustment by careless handling or by operating conditions. At the same time, if for any reason the alignment of the surfaces is disturbed, it should be capable of ready readjustment. An ideal contact would be one which is self-adjusting, both in regard to alignment of surfaces and in compensating for wear due to continued operation or severe arcing. There are several types of contacts which are more or less self-adjusting, in fact almost every contact in successful operation has this feature to some degree. The finger contact shown in Fig. 8 is self-adjusting to a considerable degree, the spring which backs the finger allowing variation in either direction from its normal position. A brush contact made up of laminations of spring copper, (Fig. 10), if properly shaped, will allow a fair amount of self-adjustment as will also a contact made up

*A curve illustrating the increased carrying capacity due to increasing pressure between contacts is given in the introductory article of this series. See the JOURNAL for November, 1907, p. 609.

as in Fig. 6. The contact which is probably self-adjusting to a greater degree than any other is the butt contact, Fig. 11. The contact spring which furnishes the pressure between the two surfaces can be made to feed the contact out to compensate for wear. This contact can be made very cheaply and for small capacity and low voltage work where the service is severe and the opening of the circuit breaker very frequent it is without doubt the most durable contact and will operate for a longer time without attention than any other form. In all these various types the spring parts which are relied upon to furnish the contact pressure must be so placed that there is no possibility of their having to carry heavy currents sufficient to cause them to heat and lose their temper.

Another important consideration is that the contacts be so formed that the burning and pitting due to arcing will not cause sticking or jamming, thus preventing the opening or closing of the device. This might easily occur in a contact of the jaw and knife blade type. It is, of course, highly desirable that the contact surfaces be easily accessible for inspection and repair. This is especially important in circuit breakers of large capacity which are subject to heavy short-circuits, as it is usually desirable to examine the contacts after the device has opened a severe overload to see if the contacts have been damaged and, if so, to repair the damage.

FIG. 8

INSULATION

The second element in the construction of the circuit breaker is the insulation, the material which separates the line contacts and current carrying parts from each other and from ground. There are several essential qualities entering into the make up of a good insulating material. It must be permanent, of sufficient mechanical strength to withstand considerable rough usage and capable of withstanding some degree of heat. As insulation is one of the prime requisites in a high tension device, considerable care and thought is required in choosing the most suitable material, making it of the best possible form, both for good service and for cheapness, and placing it to best advantage.

From the standpoint of insulation and cheapness no material

excels or even equals hard, well glazed porcelain. While it has the mechanical disadvantage of being somewhat easily broken and of

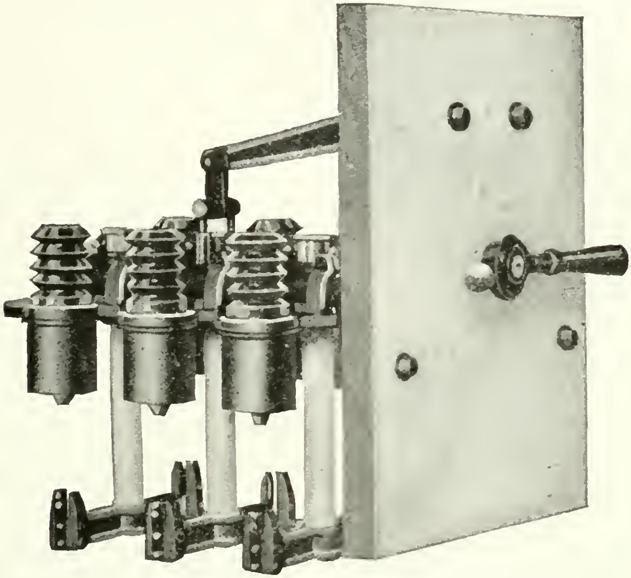


FIG. 9—OIL CIRCUIT BREAKER WITH BRUSH TYPE CONTACTS
The circuit breaker is closed by a rotary movement of the handle.

gradually developing cracks when placed under strains still, if the material is properly made, subjected to a comparatively long continued voltage test and so placed in the apparatus that the strains

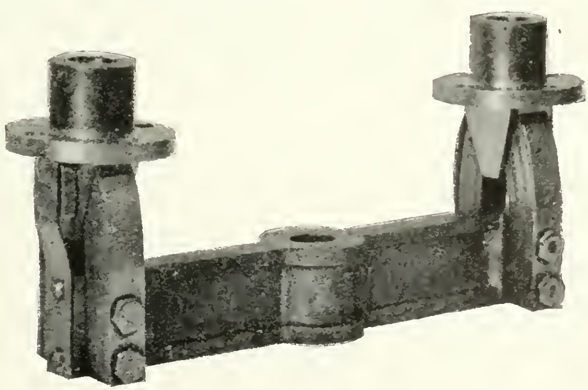


FIG. 10—DETAILS OF CONTACT SHOWN IN FIG. 9

are well distributed over the piece, there is no material that will afford a more permanent insulation. It can be used equally well in

air or under oil, which cannot be said of many materials. For instance, while hard rubber is a good insulator for use in air, being strong mechanically and having permanent insulating qualities under ordinary conditions, it cannot be used under oil or where it is possible for oil to reach it owing to its very rapid deterioration under the action of the oil.

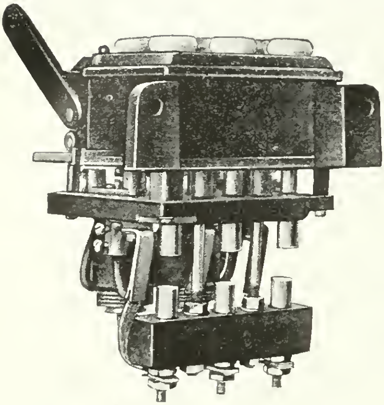


FIG. 11—A FORM OF BUTT CONTACT
Wood is used as an insulating mounting for both the stationary and movable contacts.

On the other hand, fibre is mechanically tougher than porcelain and can be used under oil with a good degree of safety and permanence, while it warps and disintegrates under the action of the atmosphere. A moulded composition is used with very good success by certain manufactures for both oil tanks and for an insulating material on which to mount the live contact parts. The material may be moulded to size in fairly complicated shapes, as may be seen by reference to Fig. 12, in which is shown a tank made of this moulded material. The interior is moulded into such a shape that in connection with the wooden rod carrying the moving contact, a very effective barrier is formed between the contacts. Protection against atmosphere action—both disintegration of the material and the absorption of moisture from the air by the material—is secured by a surface skin or glaze. Objections to the use of commercial hard fibre for making large insulators is the cost of the material, the length of time required in its manufacture and the danger that, due to attempted hastening of the curing process, traces of the chemicals used in manufacture will remain in the material, thus affecting its insulating as well as its mechanical qualities.

FIG. 12—OIL TANK MADE OF MOULDED MATERIAL AND SO SHAPED AS TO FORM BARRIERS BETWEEN CONTACTS

As noted before, well glazed porcelain is not affected by atmospheric action, will not absorb moisture even though tainted with

chemical vapors and is easily cleaned off when fouled, leaving a surface as good as originally. Neither is it softened by heat as is the case with certain composition materials, which will soften and disintegrate even under temperatures which might be reached in commercial apparatus.

Another material which is extensively used as an insulating material is wood. Dry, well seasoned wood is an excellent insulator, is easily worked into almost any desired shape, is strong mechanically, is permanent in form and insulating qualities, and has the additional asset of cheapness. If wood could be taken in its thoroughly dry and seasoned condition as it comes from the kiln, submerged immediately under oil in the apparatus in which it is to be used and kept constantly under oil, no further precaution would be necessary. Wood, however, is porous and will absorb moisture from the air, thus deteriorating in insulating value. In many cases it is desirable to use wood for insulating parts not entirely immersed in oil or entirely exposed to air. Moreover, even in parts which in service are immersed in oil, considerable time elapses between the process of drying in the kiln and using the wood in actual service. During this time it may be subjected to various atmospheric conditions during storage, shipment and installation. It therefore becomes necessary to provide some means of guarding against absorption of moisture by closing the pores of the wood. This can be done with absolute assurance only by filling the pores with some insulating material

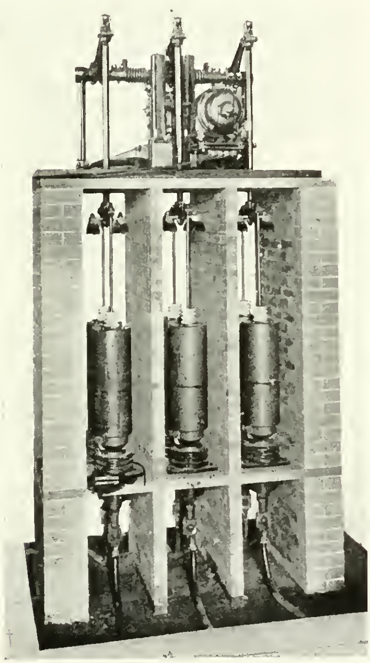


FIG. 13—ELECTRICALLY-OPERATED OIL CIRCUIT BREAKER WITH MOTOR CONTROL

The main contact brushes bridge across from one cylinder to the other in each cell. Within the oil cylinders are the auxiliary contacts on which the final arc is interrupted. The moving contacts are drawn upward to open the circuit, in which feature this apparatus differs from the other types shown.

which will not absorb moisture. If the wood is clear and free from knots, has been well soaked in water during the seasoning process and the salts entirely dissolved out, has been thoroughly dried and then effectually sealed against the entrance of moisture, it will be a very close second to porcelain in insulating qualities and very much its superior in mechanical resistance to shocks and strains. Wood is the only material which can be successfully used as an insulating base in a switch of a design such as shown in Fig. 14 or a circuit breaker as in Figs. 15 and 11. No other material would combine sufficient mechanical strength with the requisite insulating value for the supporting frames of contacts such as shown in Fig. 16.

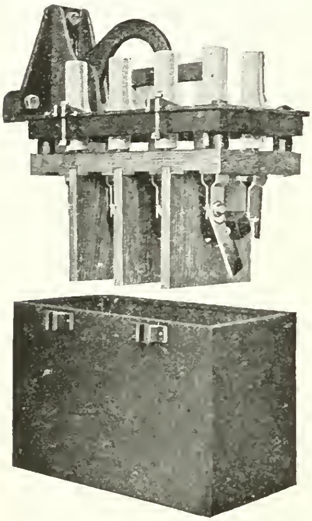


FIG. 14—OIL SWITCH FOR SWITCHBOARD MOUNTING WITH WOOD USED FOR INSULATING BASE AND BARRIERS

This switch consists of knife switches immersed in oil and direct-connected to the operating handle which is the only part of the apparatus on the front of the switchboard.

For moderate voltage service soapstone makes a good insulating material for bases for supporting contacts where good mechanical qualities are also required. A good example of this construction is shown in Fig. 17. It is not entirely reliable on high voltage on account of the liability of metallic streaks. When used on higher voltages it should receive a treatment of varnish or other insulating material.

MECHANISM

A common form of switch mechanism, consisting simply of an operating lever, with a handle grip on one end and the other end connected through a rod to the cross-bar which joins the several blades of the switch and moves them simultaneously is shown in Fig. 14. The motion is like that of the old-fashioned pump handle—pushing the handle down pulls the contact blades up into the jaws; raising the handle moves the blades down and out of contact with the jaws. It is a simple and effective mechanism, but useful only where the travel of the contacts is short, the pressures required to move them small and where a straight line motion on the rod connecting the operating lever to the contacts is not necessary. Assuming, however, that the contacts are of the conical form shown in

Fig. 6 and that the moving conical plugs must travel about seventeen inches before engaging the cups of the stationary contacts, it will be found, when the use of the single lever is attempted, that there are several defects. Unless the distance between the fulcrum and the point of attachment of the rod moving the contacts is made excessively long, the end of the lever will travel in an arc, which will impart to the moving contacts a swinging motion and the chance of the cones properly engaging the cups is remote. It, therefore, becomes necessary to provide a mechanism which will impart a straight line motion to the contacts.

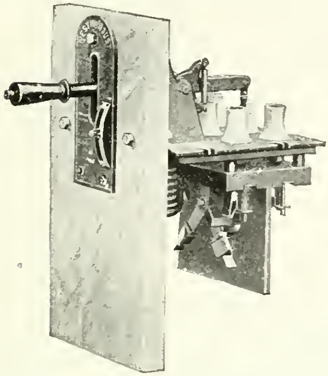


FIG 15—TWO-POLE, DOUBLE-THROW OIL CIRCUIT BREAKER

The contacts are of the wedge type and are mounted on a wooden base, the two poles being separated by a wooden barrier.

Again, in order that the operator shall not have to move the handle through such a long distance, it is desirable to make the distance from the handle to the fulcrum short. As this dimension decreases, the power which must be exerted upon the handle to move the contacts increases. Here again it is necessary to depart from the single lever arrangement and introduce a toggle by which the pressure exerted on the handle may be multiplied. The toggle is perhaps the most valuable mechanical device available in the design of circuit breakers, as almost unlimited pressures can be obtained by its use. The value of high pressures between contact surfaces has already been referred to. Not only can the toggle be utilized to furnish the pressure, but it will also maintain the mechanism in the closed position if the knee of the toggle is passed slightly beyond the dead center before coming against

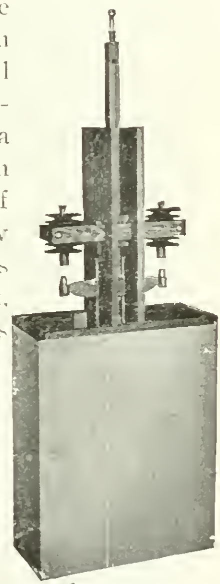


FIG. 16—CONTACT DETAILS OF A FORM OF CIRCUIT BREAKER FOR HIGH VOLTAGE SERVICE

Using wood for the supporting frame and barriers. The stationary contacts are mounted in porcelain insulators which are clamped in the wooden crossbar.

a stop. This is illustrated in the circuit breaker shown in Fig. 18. In this mechanism the contacts are closed by the direct action of the closing solenoids on the lever arms carrying them. The toggle is used only to hold the circuit breaker in the closed position. The mechanism is tripped by a hammer actuated by the trip coil, shown at the extreme left, which strikes the knee of the toggle, knocking it back beyond the dead center. This mechanism also embodies the feature of right line motion. The counterbalance springs shown above the closing solenoids absorb the momentum of the moving parts when the circuit breaker opens and also aid the magnets in closing. If this method of holding the mechanism closed is not suited to the particular design under consideration, the knee can be brought up almost to the dead center and held in that position by a latch. As the dead center position is approached, the pressure required to hold the toggle in that position is proportionally decreased.

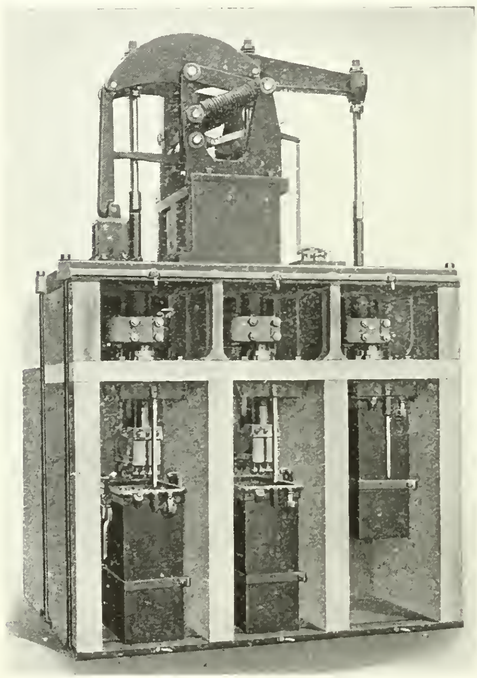


FIG. 17—HEAVY CURRENT CIRCUIT BREAKER FOR 3 300 VOLT SERVICE SHOWING USE OF SOAPSTONE FOR MOUNTING OF STATIONARY CONTACTS

Brush contacts provided with arcing plugs take the final break. A toggle mechanism is used, the solenoids acting on the toggle lever. The tripping device is similar to that shown in Fig. 20.

Either method requires a comparatively small amount of force to release from the closed position. This affords a ready means of applying an automatic release to a circuit breaker and permits the use of a very small trip coil to open it. In the design of electrically-operated circuit breakers, where solenoid operation is employed, the use of the toggle permits the employment

of comparatively small, short stroke magnets to impart a long travel and heavy pressure to the contacts. In the motor-operated circuit breaker a corresponding economy in the size of motor is effected by the use of gears. (See Fig. 13.) Another type of mechanism is shown in Fig. 19. In this circuit breaker the three poles are connected by a common shaft and the contacts are closed by direct pull

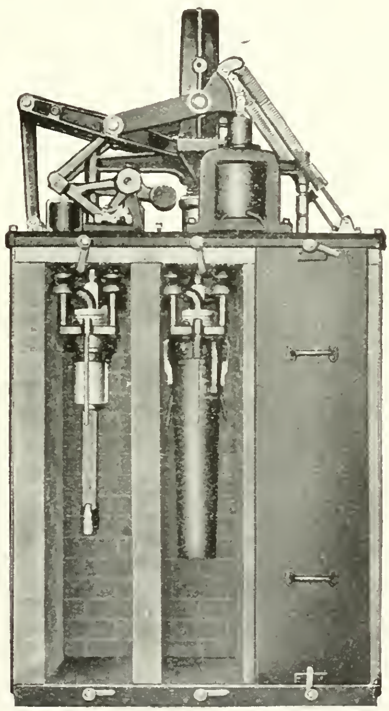


FIG. 18—OIL CIRCUIT BREAKER FOR LARGE CAPACITY, HIGH VOLTAGE SERVICE

An installation of circuit breakers of this style is shown in Fig. 5.

of the solenoid on the main lever arm and held closed by a latch. The latch is released by a trip solenoid.

The mechanism of an electrically-operated oil circuit breaker is shown in Fig. 20, in which the principles of right line motion and a certain form of toggle are illustrated. A cam is also used in connection with the toggle. The mechanism is shown in the closed position. In the mechanism the frame of the operating magnet *A* and

the tripping magnet *A'*, also the fulcrum points *1*, *2*, *3*, *4* and *5* are part of the main frame casting on the top of the circuit breaker. The contacts and the oil tank are beneath this frame, *R* being an insulating wooden rod to the lower end of which the moving contacts are attached. The operating magnet consists of a solenoid *A* having a fixed core *b* and a movable core or plunger *B*. *M* is the main lever, from the outer end of which the contact rod *R* is suspended at *7*. The lever *M* is hinged at *9* to a rocking arm *W*, which is pivoted at *2* and which is an element of the right line motion, the other element being the link *L*, pivoted at *3* and connected to the

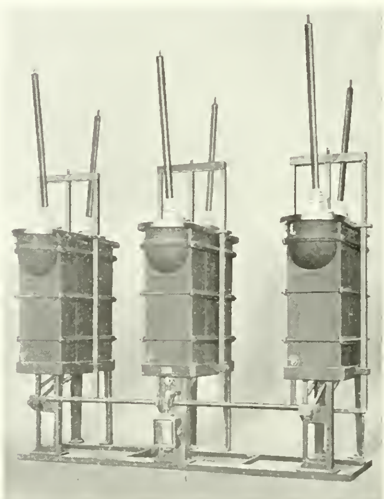


FIG. 19—HIGH TENSION OIL CIRCUIT BREAKERS FOR 88 000 VOLT SERVICE

main lever *M* at *6*. The length of the link *L* between the points *3* and *6* is the same as the portion of the main lever *M* between *6* and *9*. The link *T* forms one element of the toggle. The upper end of this link is hinged to the main lever *M* at *10*, the lower end being hinged to the cam *K* by the pin *8*. The cam, therefore, forms the second link of the toggle, the length of this link being the distance between *4*, the point about which the cam revolves, and *8*, the point of junction with the first link.

The motion of the plunger *B* of the operating magnet is transmitted to the cam *K* through the chain *C* working over the pulley *D*. The chain winds up on the face *F* of the cam, this face being

eccentric with respect to the pivot *4*. The mechanism is held in the closed position by the toggle passing slightly over the dead centre as, by reference to the illustration, it will be noted that the point *8* is slightly to the right of a line joining *4* and *10*. Further travel of the point *8* toward the right hand is prevented by the projection on the cam coming against the stop *S*. The toggle is broken and the mechanism allowed to open by the action of the tripping magnet *A'*. When the trip magnet is energized, the moving plunger *B'* is drawn into the solenoid *A'* toward the fixed core *b'*. The plunger *B'* is fastened to the outer end of the trip lever *H*, which is pivoted at *5*. When the plunger *B'* pulls down one end of the lever *H*, the

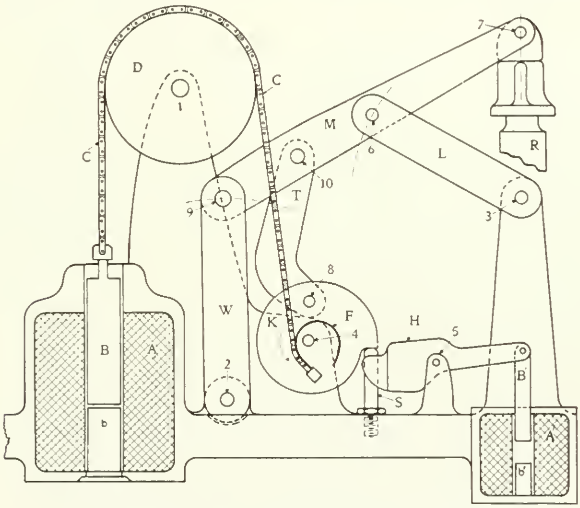


FIG. 20—MECHANISM OF ELECTRICALLY-OPERATED CIRCUIT BREAKER SHOWING TOGGLE AND METHOD OF TRIPPING

other end rises, engages the projection on the cam *K* and forces it away from the stop *S*. As soon as the point *8* passes to the left of the line joining *4* and *10* the toggle is broken and the weight of the moving parts of the mechanism and contacts causes the cam to revolve in the direction of the arrow until the point *8* reaches a position directly below the centre *4*. The point *7* on the main lever *M* falls to a position the same distance directly below the point *3* as it is above that point when the mechanism is in the closed position.

The chain winds up on the eccentric *F* and the plunger *B* of the operating solenoid *A* is raised until there is a considerable air-gap between it and the fixed core *b*. If the operating magnet is energized the plunger begins to move toward *b*. The chain unwinds

from the cam, which is rotated against the direction of the arrow, the point S forces the link T upward and the link in turn forces the main lever M upward. The advantage gained by the eccentric is that, at the beginning of the stroke of the magnet where the air-gap is longest and therefore the pull of the core least, the chain pulls on the long arm of the eccentric; as the air-gap decreases and the pull becomes stronger, the chain pulls on a constantly decreasing arm. The tendency is therefore to make the pressure applied to the point S equal throughout the entire travel of the magnet. This is a very desirable condition as the toggle action will furnish any increase in pressure which may be necessary when the contacts are closed.

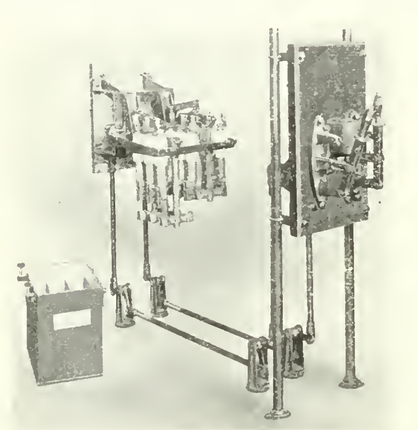


FIG. 21—HAND-OPERATED, REMOTE-CONTROL CIRCUIT BREAKER
Three-pole, double-throw with automatic overload release coil mounted on the panel. The circuit breaker may also be tripped by hand.

By the use of the mechanism, a travel of three inches on the plunger of the operating magnet is converted into a travel of twelve inches on the contacts, the contacts being moved in a vertical path with no side swing.

As has already been intimated, in installations employing comparatively low voltages, the circuit breakers are mounted directly on the switchboard panels, the operating handle projecting through to the front of the panel. For higher voltage work, or where peculiar conditions of installation are encountered, circuit breakers with remote mechanical control are often used. Fig. 21 illustrates such a circuit breaker in which bell cranks and rods are used for the remote control mechanism. The length of the connecting rods may be varied to suit the conditions of installation. The illustration shows the application of the remote control principle to a double-throw circuit breaker, two handles and two sets of bell cranks and rods being used, both handles being automatically released by a common trip coil.

Aside from the essential features of the mechanism of a circuit breaker which provide for the opening and closing of the contacts and the maintaining of the contacts in either position, it is pos-

sible to provide a great variety of special features. It may be stated as fundamental, that the fewer there are of these special features the more reliable will be operation of the apparatus. Too great stress cannot be laid on the necessity of a mechanism having as few complications as possible. Notwithstanding this, conditions are sometimes encountered where the advantages to be gained by the introduction of certain non-essential features outweigh the objections to

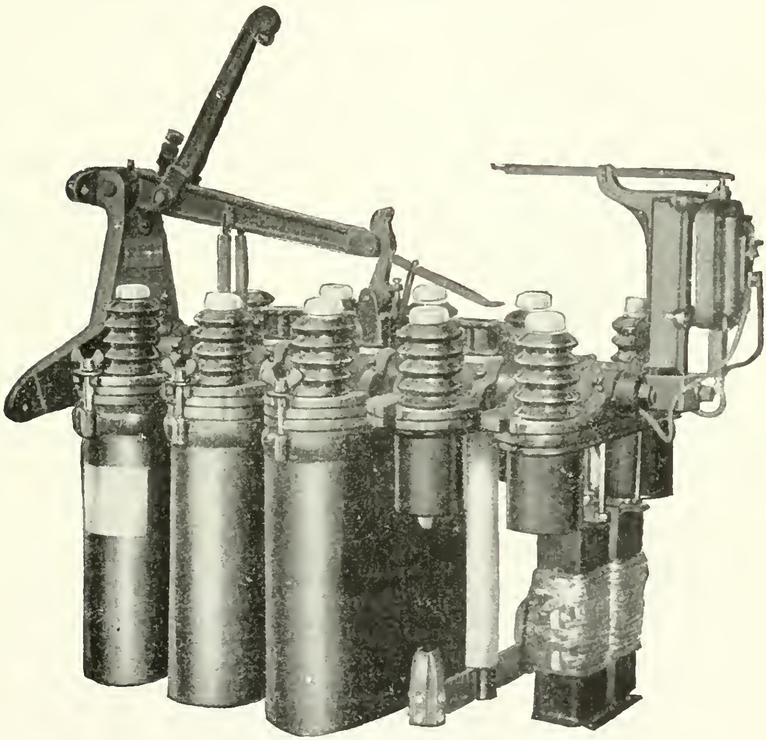


FIG. 22—REMOTE-CONTROL OIL CIRCUIT BREAKER

The two oil-insulated series transformers for operating the automatic overload release coils are enclosed in oil tanks similar to those used to enclose the contacts, one of each kind being shown with tank removed. The non-closable-on-overload feature is provided for in the construction of the tripping mechanism.

their use. Thus, circuit breakers are often provided with automatic trips, with the "non-closable-on-overload" feature, or the remote control feature, as well as with the various arrangements for operation on under-voltage, with shunt trips and in connection with relays. Fig. 22 shows a circuit breaker having the first three of the above special features, the series transformers for energizing the automatic trip coils being embodied in the circuit breaker itself.

The remote control mechanism consists of pulleys and wire cable. The cable is attached to the lever arm shown projecting upward in the cut. A suitable handle is provided on the switchboard panel for the attachment of the other end of the cable.

In the design of a piece of apparatus the service to which it is to be applied and the conditions under which it is to operate must of necessity determine the details, and it is the task of the designers

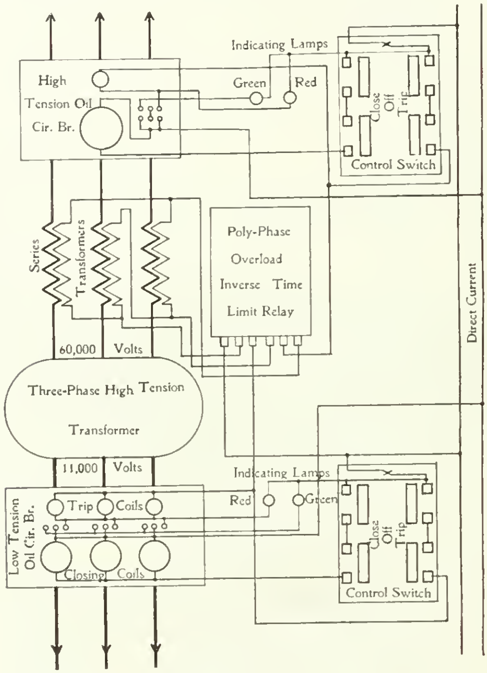


FIG. 23—CONNECTION DIAGRAM OF CONTROLLING AND INDICATING APPARATUS FOR TWO OIL CIRCUIT BREAKERS USED TO AUTOMATICALLY PROTECT BOTH HIGH AND LOW-TENSION SIDES OF A THREE-PHASE, HIGH-TENSION TRANSFORMER

to meet these conditions without departing too far from what are known to be the most desirable principles of construction. Some peculiar conditions of installation often may be turned to good account in effecting economy of material or ease of access without serious sacrifice in other directions. All designs must be more or less of a compromise and the best results will be obtained by the person who can best weigh the relative merits of the desirable features, not giving undue prominence to one and losing sight of another of equal importance.

VECTOR DIAGRAMS APPLIED TO POLYPHASE CONNECTIONS

HAROLD W. BROWN

IT is possible to make connections to polyphase circuits in so many different ways that care must be exercised to determine which of these connections gives the right combination of currents or e.m.f.'s, and which gives the right phase relations between them. This paper aims to show by the use of vector diagrams the right connections for some of the more common polyphase circuits. In order that the discussion may be complete, it begins with elementary principles. The conclusions have special reference to an article to appear in a subsequent issue of the JOURNAL, but they apply as well to all polyphase circuits.

REPRESENTATION OF ALTERNATING CURRENTS

One method of representing an alternating current is by a curve in which horizontal distances indicate time and vertical distances instantaneous values of current. Usually such a curve approximates

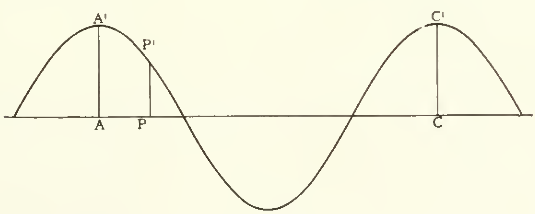


FIG. 1

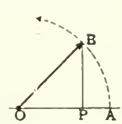


FIG. 2

a sine curve such as is shown in Fig. 1. This method appears simple, but it is difficult to use. A more useful method is shown in Fig. 2, in which OB is a line of constant length, rotating at a uniform rate about O as a center. BP is perpendicular to OA, so that as the point B moves in a circle, the point P is at variable distances from O, first to the right and then to the left. Calling distances to the right of O positive and to the left negative, it is evident that OP has alternately positive and negative values, and that these values vary from zero to a definite maximum. They pass through a complete cycle of changes from positive to negative and back to positive while the line OB makes one revolution, which corresponds to the distance AC in Fig. 1. The length OP, in Fig. 2, varies as the sine

of the angle *OBP*, and thus *OP* may be used to represent the instantaneous value of an alternating current of sine wave form whose maximum value is measured by *OA*. *OA* and *OP* correspond to and are equal to *AA'* and *PP'* respectively, in Fig. 1. The time that has elapsed since the current had a positive maximum value is proportional to the length of the arc *AB*. This time is represented by *AP* in Fig. 1. Just as *OA* measures the maximum, and *OP* the instantaneous value, so both maximum and instantaneous values are represented by *OB*, for the length of *OB* is the same as the maximum value *OA*, and its projection on the horizontal is the instantaneous value *OP*. On this account it is customary to use only the line *OB* to represent an alternating current, leaving the imagination to supply *OP* and *OA*. Usually an arrow-head is put on *OB* pointing outward, as shown.

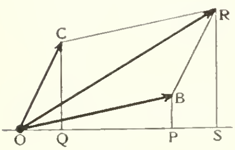


FIG. 3

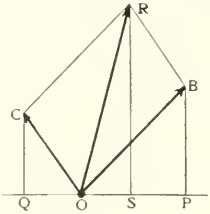


FIG. 4

It is necessary in developing the principles to take account of the instantaneous values, but afterward they are little used. In practical applications it is most important to know what is the maximum value of the current and what part of a cycle elapses between this and the maximum value of some other current or e.m.f.

Sum of Two Currents —In Figs. 3 and 4, *OB* and *OC* are two alternating currents having the same frequency, but not in phase with each other. The rotating line *OC* is always ahead of *OB* by a constant angle, *COB*, i. e., *OC leads OB*, or *OB lags* behind *OC* by the angle *COB*. The projections *OP* and *OQ* represent the instantaneous values of *OB* and *OC*. *BR* is drawn parallel to *OC*, and *CR* to *OB*. *OQ* is the projection of *OC*, and *PS* of *BR*. Since *BR* is equal to and parallel to *OC*, *PS* is equal to *OQ*; hence the *algebraic* sum of the two instantaneous currents $OQ+OP=OS$. Furthermore, *OS* is at all times the projection of *OR*, so that *OR*

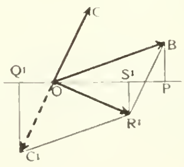


FIG. 5

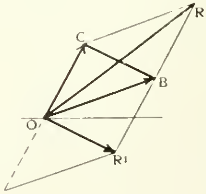


FIG. 6

represents the sum of the two alternating currents,* in the same way that OB represents one current.

Difference of Two Currents—In Fig. 5, OC represents an alternating current and OC', drawn equal and opposite to OC, represents the same current in the opposite direction, i. e., it represents minus OC. As in the case of the sum of two currents, OP is the projection of OB, OQ' of OC' and PS' of BR'. The algebraic sum of OP and OQ' is OS', which is the projection of OR'. Therefore, OR' represents the sum of the currents OB and OC', i. e., OR' represents the current OB minus the current OC.

In Fig. 6, the diagonal CB of the parallelogram $OBRC$ is equal and parallel to OR'. This diagonal, which does not pass through the center O, may then be used to represent the difference of two currents, just as the diagonal OR passing through the center O represents the sum. To represent current OB minus current OC the

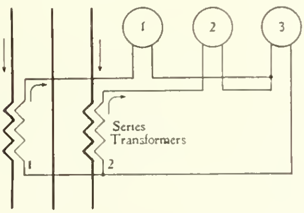


FIG 7

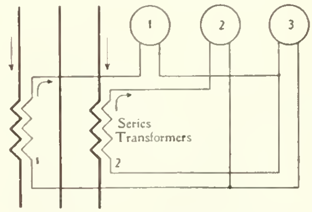


FIG. 8

arrow on CB should point towards B. To represent current OC minus current OB, it should point towards C.

If OB and OC were rotating in coincidence, i e., if they were in phase with each other, the line representing their sum would be equal in length to $OB+OC$ and the difference equal in length to $OB—OC$, but if they are not in phase, the sum is numerically less than $OB+OC$, and the difference numerically greater than $OB—OC$. This fact is readily verified experimentally by connecting three ammeters to two series transformers, as shown in Figs. 7 and 8. In Fig. 7, ammeter *3* measures the sum of currents *1* and *2*. If *1* and *2* are in phase with each other, the reading on ammeter *3* will

*Two further conditions to be imposed on OR (as well as on OB as stated above), are that it must be of constant length and rotate with uniform angular velocity. These conditions are evidently fulfilled, for OB and OC are of constant length, and having the same frequency, their angular velocities are the same. Therefore, the angle between them is constant, and the entire parallelogram $OBRC$ rotates about O without changing its shape. OR, being a part of the parallelogram, has a constant length and a uniform angular velocity.

be numerically equal to the sum of the readings on ammeters *1* and *2*. If they are not in phase, ammeter *3* will read numerically less than the sum of the other two. In Fig. 8, ammeter *3* reads the difference of currents *1* and *2*. If *1* and *2* are in phase with each other, the reading of ammeter *3* will be numerically equal to the difference of the readings on ammeters *1* and *2*. If they are not in phase, ammeter *3* will read numerically more than the difference of the other two; in fact, it will usually be found that the ammeter reading the difference carries more current than do either of the other meters.

REPRESENTATION OF ALTERNATING E.M.F.'S

All the preceding discussion applies to alternating e.m.f.'s as well as to alternating currents. The e.m.f. between two conductors is the difference between the respective e.m.f.'s of the two conductors. For example, the alternating e.m.f. of the conductor *B* is represented by the line *OB* in Fig. 6; i. e., *OB* indicates how much *B* is above or below zero. At the same time another conductor, *C*, has an alternating e.m.f. represented by *OC*. The alternoting e.m.f. between the two is the difference between the e.m.f.'s, which is represented by the line *BC*. If the arrow is pointed towards *C*, the e.m.f. represented by it is *C—B*, or the amount that *C* is above *B*. If it is pointed towards *B*, the e.m.f. is *B—C*, or the amount that *B* is above *C*.

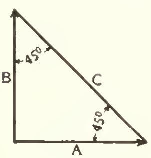


FIG. 9

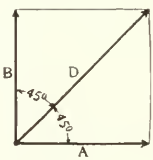


FIG. 10

APPLICATION TO TWO-PHASE CIRCUITS

E.m.f. Relations—The e.m.f. of one phase is at its positive maximum at a time midway between the times of positive and negative maxima of the other phase. The two e.m.f.'s which are represented by the lines *A* and *B* in Fig. 9 are 90 degrees out of phase with each other; in other words, there is an angle of 90 degrees between the lines *A* and *B*. Where there is one wire common to the two phases (as is the case with the two-phase three-wire system), the e.m.f. between the other two wires is represented by *C*. If the e.m.f.'s *A* and *B* are equal, $C=2\,A\cos 45$ degrees$=1.41\,A$. The direction of the arrow on *C* depends on whether *A* or *B* is arbitrarily considered positive.

Current Relations—If the current of each phase is in phase with its e.m.f., or if each lags or leads by the same amount, the currents are 90 degrees out of phase with each other. They are represented by A and B in Fig. 10. If one wire is common to the two phases, the current in this wire is represented by the diagonal D, for this current is the sum of the other two. With these conditions if $A=B$, then $D=1.41\ A$. It is interesting to notice that at 100 per cent power-factor, the current D, Fig. 10, and the e.m.f. C, Fig. 9, are 90 degrees out of phase with each other.

THREE-PHASE CIRCUITS

E.m.f. Relations—In this case there are three e.m.f.'s represented in Fig. 11 by A, B and C. The time intervals between the successive e.m.f.'s are all equal, the angle between them is therefore 120 degrees. It should be remembered that A, B and C represent the e.m.f.'s of the various lines, i. e., the e.m.f.'s from the respective

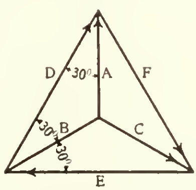


FIG. 11

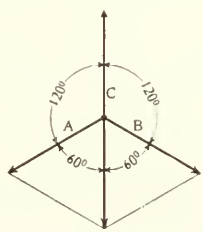


FIG. 12

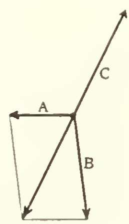


FIG. 13

lines to neutral and not each the difference between one line and another. The e.m.f. between A and B is represented by D, and that between B and C by E, and that between C and A by F. The directions of the arrows on D, E and F may be chosen arbitrarily, depending on whether they represent $A—B$ or $B—A$, etc. As they are shown, they represent $A—B$, $B—C$ and $C—A$. If A, B and C are all equal, D, E and F are equal. In this case $D= 2\ A\ \cos 30$ *degrees*$=1.73\ A$. It will be noticed that not only A, B and C, but also D, E and F (the e.m.f.'s between the lines) are 120 degrees apart, and that each is 30 degrees out of phase with one of the original e.m.f.'s, A, B or C.

Current Relations—If each line were connected through a non-inductive resistance to a neutral point, the current in any line flowing toward the neutral point would be in phase with the e.m.f. between that line and the neutral, for the current would be positive when the e.m.f. is positive, and would be at every instant propor-

tional to the instantaneous e.m.f. In such a case the current would be in phase with its e.m.f., *A, B* or *C,* Fig. 11, whereas the external e.m.f.'s (i. e., the e.m.f.'s between the lines), are *D, E* and *F*. It is important to get this clearly in mind, for *D, E* and *F* are the e.m.f.'s that are available to be measured, and it is sometimes confusing not to find the currents in phase with these e.m.f.'s.

Instead of flowing through a non-inductive resistance to a neutral point, the current usually passes through a motor armature or some other circuit having in it an induced e.m.f. The case of the non-inductive resistance is given merely as an example in which the current is in phase with its e.m.f., i. e., it shows what happens in any case at 100 percent power-factor. If the conditions of the circuits are varied, any phase relationship may be established between currents and the corresponding e.m.f.'s; the greater the phase angle between them, the less the power-factor.

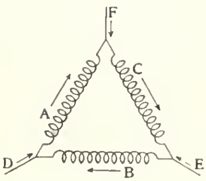


FIG 14

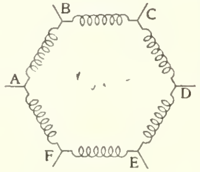


FIG. 15

The sum of two currents *A* and *B* may be found by completing the parallelogram as shown in Fig. 12. If the three currents, *A, B* and *C* are all equal and 120 degrees apart, it is at once evident that $A+B$ is equal and opposite to *C*. Consider the currents in any three-phase, three-wire system, as in Fig. 13. The various currents may not be equal, and the phase angles between them may not be equal, but the total current that flows from the generator is the same as that returning to it—i. e., the sum of the currents on any two lines is the same as that on the other line, but in the opposite direction.* This statement applies to both instantaneous and maximum values.

Delta-Connected Circuits—In the case of a three-phase rotary converter or any other delta-connected apparatus, the current in each of the external circuits divides as it enters, as illustrated in Fig. 14. It is convenient to assume the positive directions of the currents in the windings in a clockwise direction, as indicated by the arrows. With this assumption, representing by *A, B, C, D, E*

*In the case of the three-phase four-wire system (i. e. with "ground return"), the sum of the currents on any three lines is the same as that on the other line, but in the opposite drection. Similarly, the current in all but one of any number of lines is the same as that in the other line with its direction reversed.

and *F*, the currents in the circuits having corresponding letters, *D*=*A*—*B*, *E*=*B*—*C*, *F*=*C*—*A*. If *A*, *B* and *C* are equal, and 120 degrees apart, *D*, *E* and *F* are equal, and *D*=1.73 *A*. As in the case previously discussed, each external current is 30 degrees out of phase with an external e.m.f. at 100 percent power-factor. Ordinarily the e.m.f. between external points is the only e.m.f. to be considered with reference to the delta-connected circuits, but if the e.m.f. from an external point to neutral is desired, it may be determined as already indicated.

SIX-PHASE CIRCUITS

Even where six-phase power is used, it is customary to transmit it three-phase and change it to six-phase in the step-down transformers. Six-phase rotary converters are frequently connected to transformers in this manner; for they have advantages over three-phase rotary converters, whereas the six-phase transmission lines would have no advantage over three-phase lines. There are two methods of making connections to the rotary converter, one known as the "double delta" and the other as the "diametrical" connection. With either of these connections, six collecting rings are used, whose successive e.m.f.'s are at phase angles of 60 degrees from each other, as shown in Fig. 15.

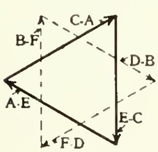


FIG. 16

The Double-Delta Arrangement has two independent sets of connections, each the same as for three-phase delta-connections. In Fig. 15, *A*, *C* and *E*, would be used for one delta and *B*, *D* and *F* for the other. The six e.m.f.'s between the external points of the two deltas are represented in Fig. 16, with the arrows in each delta pointing in a clockwise direction. It will be seen that each e.m.f. of one delta is exactly in phase with an e.m.f. in the other delta, but in the reverse direction. For example, *F*—*D* is in phase with *C*—*A* reversed, i. e., in phase with *A*—*C*. By using transformers with double secondary windings, it is therefore possible to connect *F*—*D* to one, and *A*—*C* to the other secondary of the same transformer and to make similar combinations in the other phases. Fig. 17 shows the connections of one delta of the rotary converter to one set of secondaries of the transformers. The other delta is connected to the other set of secondaries at points indicated by corresponding letters. For simplicity, the actual connections of the second delta are omitted from the diagram. As in the cases previously con-

sidered, external current is 30 degrees out of phase with external e.m.f. at 100 percent power-factor.

In case the primaries of the transformers are delta-connected and the secondaries Y-connected (with double winding), the phase relation between the line and the rotary converter is changed by 30 degrees, whereas if primary and secondary are both delta-connected, or both Y-connected, the external currents and e.m.f.'s of the rotary converter are in phase with the corresponding line currents and e.m.f.'s. However, this need not affect any measurements on the rotary converter, because it still has the double-delta connection and the phase relation between currents and e.m.f.'s of the rotary converter are the same in any case.

The Diametrical Connection is different from the double-delta, in that only one secondary circuit of each transformer is required, and instead of connecting to points on the rotary converter 120 degrees apart in phase, each transformer connects to points of opposite polarity (180 degrees apart) as shown in Fig. 18. The three circuits are from *A* to *D*, from *B* to *E* and from *C* to *F* in Fig. 15. The three e.m.f.'s are 120 degrees apart, as shown in Fig. 19. Assuming that all the diametrical e.m.f.'s are equal, the e.m.f. from any outside point to neutral is one-half that from any point to the point diametrically opposite. At 100 percent power-factor, the external currents are in phase with the corresponding e.m.f.'s. If one of the pairs of connections (*B* and *E*, for example) is reversed and the others are left unchanged, as in Fig. 20, the three e.m.f.'s will be 60 degrees apart instead of 120 degrees. Of course this is wrong, for these circuits are connected to transformers whose e.m.f.'s are 120 degrees apart.

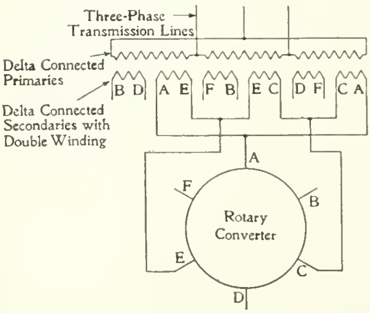


FIG 17

SUMMARY

This treatment and application of vector diagrams may be reviewed as follows:—

(1) An alternating current or e.m.f. may be represented by a rotating line. The instantaneous value is represented by the projection of the line on the horizontal; the maximum value by the

length of the line. Phase difference between currents or between e.m.f.'s or between a current and an e.m.f. is indicated by the angle between lines representing the current or the e.m.f. under consideration.

(2) If two alternating currents or e.m.f.'s are represented by two lines, as above, starting from the same center, and if two more lines are drawn parallel to these, completing the parallelogram, then the sum of the two currents or e.m.f.'s is represented by the diagonal passing through the center of the parallelogram; and the difference of the two currents or e.m.f.'s is represented by the other diagonal (not passing through the center).

(3) The alternating e.m.f. between two points is the difference of the e.m.f.'s of the two points as found in (2).

(4) In two-phase circuits the e.m.f.'s of the two phases are 90 degrees apart. With two-phase three-wire connections, the e.m.f. across the outside lines is the difference of the e.m.f.'s, as found in (2). If the original e.m.f.'s are equal, the difference is 1.41 times either e.m.f., and 45 degrees out of phase with each. The current in the common line is the sum of the currents in the outside lines, as found in (2). If the currents in the outside lines are equal, and each has the same phase relation to its e.m.f., the current in the common line is 1.41 times either of the outside currents, and is 45 degrees out of phase with each of them.

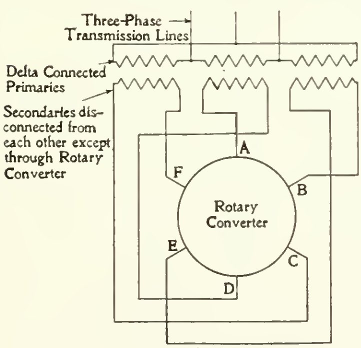


FIG. 18

(5) In three-phase circuits the e.m.f.'s (A, B, C) between the respective lines and neutral are 120 degrees apart. The e.m.f.'s (D, E, F) between different lines are also 120 degrees apart, and each of the latter is 30 degrees from one of the former. At 100 percent power-factor, the currents in the external lines are in phase with the e.m.f.'s between the respective lines and neutral. They are therefore 30 degrees out of phase with the e.m.f.'s between different lines. If e.m.f. $A=B=C$ then $D=E=F=1.73\ A$. If all the currents in the delta are equal and at equal phase angles from each other then each external current is equal to 1.73 times each current inside the delta.

(6) In any system of transmission lines the current in one

line is the same as that in all the others combined, but in the opposite direction.

(7) Six-phase rotary converters may be connected to three-phase lines by either "double-delta" or "diametrical" connections. In the former case the current and e.m.f. phase relations of each

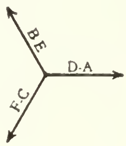


FIG. 19

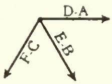


FIG 20

delta are identical with those of three-phase delta connections. In the latter case, each of three transformers is connected to diametrically opposite points on the rotary converter. The three diametrical e.m.f.'s are 120 degrees apart, and assuming that they are all equal, each is exactly twice the e.m.f. from any external e.m.f. to neutral.

PROTECTIVE RELAYS (Concl.)

M. C. RYPINSKI

DIRECT-CURRENT DEFINITE TIME LIMIT RELAY

AUXILIARY

WHERE a definite time element action has not been provided for, this auxiliary relay may be employed. It is adjustable only as to time element and serves as an auxiliary relay to close the tripping circuit a definite length of time after its own actuating circuit has closed. It is chiefly used in connection

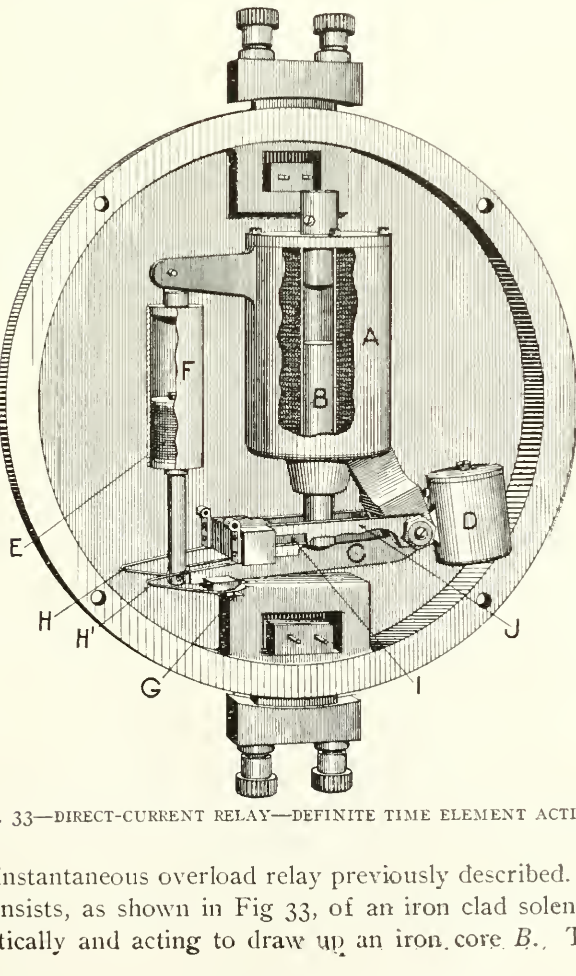


FIG. 33—DIRECT-CURRENT RELAY—DEFINITE TIME ELEMENT ACTION

with the instantaneous overload relay previously described.

It consists, as shown in Fig 33, of an iron clad solenoid *A* located vertically and acting to draw up an iron core *B*. This core,

as it rises, relieves a lever arm *C* (on which it normally rests) of sufficient weight to allow a counter-balance *D* to act by gravity, drawing down the right hand end of *C* and thereby forcing up an air dash pot piston *E* working in the pivoted cylinder *F; E* being connected to *C* at its left end. Piston *E* and cylinder *F* are so fitted that a certain time is necessary to allow the air ahead of the piston to be forced out, thus giving the time element feature to the relay. Mounted on *C* is a moving contact *G* which in its upward travel meets and connects the stationary insulated contacts *H-H'*. These contacts form the closing part of the trip circuit. Contacts *H-H'* are adjustably supported by means of a pin forming a part of a lever attached to the relay cover (and not shown), the pin bearing in the

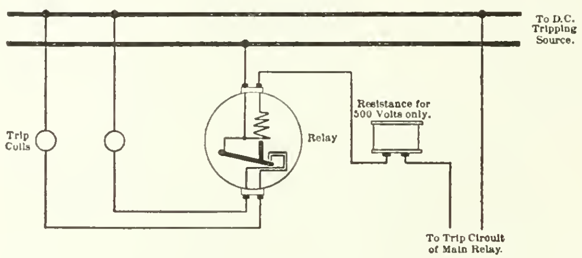


FIG. 34—CONNECTION DIAGRAM
Auxiliary direct-current definite time limit relay for use in connection with overload relay.

slot *I* of the contact lever frame *J*. They can be moved relatively to the contact *G* by means of the lever handle which extends through the relay cover. This forms the adjustable time element feature of the device, as the nearer *H-H'* are to *G*, the less time necessary for closure and vice versa. Solenoid *A* is connected through the trip contacts of the main relay to the direct-current tripping source.

Upon closure of the main relay contacts the solenoid *A* is energized and after a definite interval, determined by the dash pot clearance and the setting of handle *I* on the outside of the case, the contacts *G* and *H-H'* close, actuating the tripping coil of the circuit breaker. When the circuit breaker trips, the main relay opens thus de-energizing solenoid *A*, and core *B* commences to descend carrying with it the lever arm *C* and its mechanism. This descent takes place rapidly, a valve in piston *E* opening to admit the air and the relay is then ready for the next action of the main relay. This type of relay is connected to the main relay as shown in Fig. 34.

DIRECT-CURRENT RELAY SWITCH

AUXILIARY

The relay switch shown in Fig. 35 is used in connection with a main relay when the current required to open the circuit breaker is greater than the current-carrying capacity of the main relay contacts. An iron-clad solenoid actuating an iron core so as to draw up a conducting disk against two trip contacts constitutes the main feature of this relay. The solenoid is energized from a direct-current source, usually the same as that of the tripping circuit. The resetting or restraining force is gravity. This relay is connected to the circuit as shown in Fig. 36.

FIG. 35—DIRECT-CURRENT RELAY SWITCH

BELL RELAY

AUXILIARY

The bell relay shown, with cover removed, in Fig. 37, serves to indicate when a circuit breaker has operated by energizing a gong circuit and maintaining this circuit until the same is opened by the switchboard attendant.

It is usually installed in combination with a main relay connected so that when the latter operates it also actuates the bell relay. The advantage of such an arrangement over a mechanically closed relay connected directly to the circuit breaker mechanism lies in the fact that with the bell relay, if the circuit breaker is opened by the controlling switch, no alarm will be sounded.

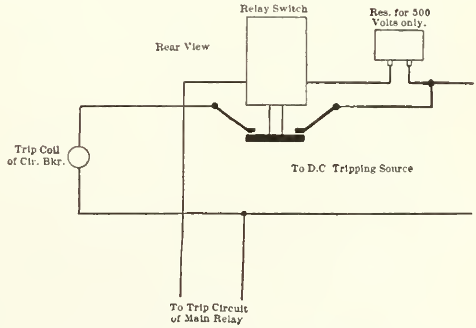


FIG. 36—CONNECTION DIAGRAM

Direct-current relay switch used in connection with main relay when large contact current-carrying capacity is required.

From Fig. 38 it may be seen that this relay consists of two independent electro-magnets *B* and *C*, actuating an iron armature *A* so as to close a pair of contacts. *A* is under the influence of no restraining or resetting force except gravity. Its downward motion is limited by a stop. Five terminal leads extend through an insulated terminal block at the base of the relay. The coil *B* is connected in the tripping circuit of the circuit breaker through the trip contacts on the main relay. When the overload relay operates it energizes *B*, which pulls up *A*, closing the contact, which on closing energizes coil *C* and an alarm gong through the push button switch, current being supplied by the direct-current source through an independent circuit. Immediately, however, upon the closure of the main relay contacts, the tripping coil of the circuit breaker operates, de-energizing the line and the overload relay and as a result the coil *B*. Sufficient time has elapsed, however, for the bell relay to close its contacts and throw in coil *C*, which, upon the failure of the current in *B*, takes up the entire load of the armature and maintains the gong circuit until an attendant, by means of the push button switch, de-energizes the circuit of *C*, allowing *A* to drop and restoring the original circuit condition.

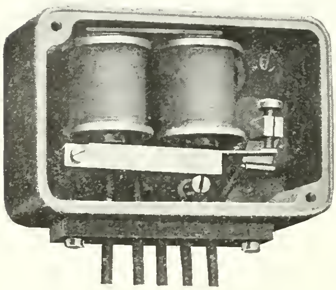


FIG. 37—BELL RELAY

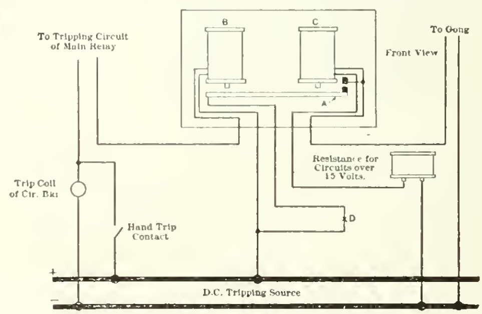


FIG. 38—CONNECTION DIAGRAM

Showing arrangement of electro-magnets and circuits of bell relay used in connection with overload relay.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

80—Copper Loss in Generators. What is the copper loss in a two-phase mesh-wound generator in terms of the line current I and the resistance R as measured between terminals, R being the equivalent resistance measured between terminals on either phase? Also, for a single-phase generator? What is the current, in each case, in terms of the current in each coil of the armature and why?
H. M.

For two-phase mesh winding the copper loss is $\frac{1}{2}$ I^2R. For single-phase winding the copper loss is I^2R. For two-phase mesh connected winding I equals $2\ i$, where I equals total current and i equals current in line. Current in line divided by $\sqrt{2}$ equals current in coil. For two-phase open winding the current in the line equals current in coil, the same as for single-phase winding. In any kind of a single-phase winding the copper loss is equal to the product of the square of the line current multiplied by the resistance measured between the two terminals. In any kind of two-phase or three-phase generator, transformer, motor, transmission line or other apparatus the equivalent resistance is $\frac{1}{2}$ of the resistance measured from terminal to terminal and the equivalent current is the line current multiplied by $\sqrt{2}$ in case of two-phase apparatus and in the line current multiplied by the $\sqrt{3}$ in case of three-phase apparatus. In any kind of polyphase apparatus the copper loss is the product of the square of the equivalent current and the equivalent resistance. This rule is developed by the simple analysis of the winding, by calculating the copper loss in each individual branch of the winding and then adding all of these values to obtain the total copper loss. The rule of parallel resistance and the $\sqrt{2}$ and $\sqrt{3}$ relations of currents for various circuits will furnish all the necessary mathematics. For details of this calculation see an article by Mr. Workman on p. 612-3-4, Vol. I. of the Journal and by Prof. Karapetoff on p. 471-2-3, Vol I.

81—Grounding of Transformers Operating Rotary Converters. The neutral point of the secondary windings of step-down transformers operating in connection with a rotary converter is grounded. The direct-current circuit supplies 550-volt motors operating in industrial service, there being, therefore, a metallic return circuit (that is insulated from ground). Will the direct-current system be grounded also and thus violate Section 34, National Electrical Code?
F. D. W.

This case is not covered directly by the National Electrical Code. The case which is most nearly applicable is that of a three wire, direct-current generator with the middle wire grounded, in which the voltage from either direct-current line to the ground will be one-half of the line voltage. Rule 34 of the National Electrical Code is framed to apply to railway circuits where one side of the direct-current circuit carrying from 500 to 650 volts is connected directly to the ground. The following explanatory note relative to Section 34, quoted from the book of rules of the Mutual Fire Insurance Companies shows that this section of the Code is not applicable to the above stated case:

"Lighting from trolley wires is forbidden because of the danger of introducing into a building a circuit which has so much capacity back of it and which is thoroughly connected to the earth on one side. The inevitable fluctuation in voltage would also frequently require over-fusing of

the lighting circuits to prevent blowing fuses under normal conditions."

C. E. S.

82—Why are the Air-gaps between the fields and armatures of turbo-generators made so great? In some cases it is one and one-half inches or more. In other electric machines the air-gap is so small that the field pieces and armature almost touch. H. M.

Efficient operation of steam turbines requires that they be run at much higher speeds than is desirable with reciprocating engines. With turbo-generators running at these higher speeds it is necessary that there be a small number of poles in order to secure the desired frequency. With a given size of machine the number of poles is limited by the speed required to give good steam turbine performance. Also since output is always proportional to speed, high speeds are desirable. With such a design, the armature reaction per pole is large and therefore a strong magnetic field per pole is required. This necessitates a large air-gap. If such a generator had a smaller air-gap the amount of magnetization necessary to give full-voltage at no-load would be small compared with that required to give full-voltage at full-load. As the air-gap is increased the field strength for full-voltage at no-load has to be increased almost proportionately. The effect of the armature reaction is less, therefore, because of the large air-gap and the desired percent regulation (that is, percent variation in voltage from no-load to full-load) is obtained. A reduction of this air-gap means a greater variation in voltage from no-load to full-load. For further explanation see the Journal for June, 1904, p. 201.

83—Parallel Operation of Rotary Converter and Railway Generator. A 600-volt rotary converter is to operate in parallel with an engine-driven 600-volt railway generator. Both machines equalize on the positive side, the positive sides being connected to the trolley and the negative sides to the ground. In case of an interruption to the alternating-current supply to the rotary, the latter would be driven as a motor by current from the direct-current generator. With a reverse current relay and a shunt trip coil on the direct-current circuit breaker of the rotary converter the breaker would immediately trip out on reversal of current, but it is thought that the rotary would still continue to operate as a direct-current motor taking current through the equalizer. Under the above conditions, what arrangements can be made so that the rotary will be automatically disconnected from the direct-current generator and stop? L. W. B.

The reverse current relay should be connected so as to operate two circuit breakers, one in the positive side of the line and one in either the equalizer circuit or the negative side of the line. If the relay contact has not sufficient carrying capacity to trip two circuit breakers, an auxiliary relay switch operated by the relay may be employed; the relay switch contact to have ample carrying capacity to operate the circuit breakers.

H. W. B.

84—Are Electrolytic Rectifiers Considered Practical; what is the capacity limit; what is the average efficiency; what effect do they have on the power-factor of the circuit; what are the alternating-current and direct-current voltage limits; what electrolyte should be used with an aluminum cell? A. G. G.

Electrolytic rectifiers are considered practical for small loads. The capacity is limited by the heating of the cells. An efficiency of 60 percent is very good. With a cell working properly a good average commercial efficiency of 50 percent may be obtained. The power-factor is never above 90 percent, but is not necessarily low if the cell is operating at full-load. On the alternating current side an average effective voltage of 175 volts per cell is about the maximum that can be used with the cell maintained at the proper operating temperature. This gives

about 55 volts per cell on the direct-current side. Ammonium phosphate or sodium phosphate are the electrolytes most recommended for use in the aluminum electrolytic rectifier. Several commercial forms are on the market and more detailed information regarding their performance may be obtained from the manufacturers. L. W. C.

85—ELECTROLYTIC RECTIFIER. What is the best and cheapest way to make an electrolytic rectifier to charge automobile storage batteries of about 25 amperes capacity? I saw one recently that was made by immersing an aluminum and an iron electrode in a common battery jar containing a solution of ammonium phosphate. The only trouble it gave was that a coating seemed to finally cover the plates and stop the flow of current. In one of the weekly electrical papers I saw an answer to a similar question which simply said, "make a neutral solution" of the same material. How is a neutral solution made? Also let me know the best method of regulating the direct-current voltage of such a rectifier. F. T. K.

Probably the most practicable electrolytic rectifier employs ammonium phosphate for the electrolyte with iron and aluminum elements. The coating on the aluminum plate is what gives the cell its rectifying properties and should not seriously stop the flow of the current if the solution is strong and kept at a low temperature. Ammonium phosphate is very soluble in water and the solution should be strong and free from impurities. Distilled water should be used and care should be taken that the salt is pure ammonium phosphate and not the double phosphate of ammonium and sodum or ammonium and potassium. A neutral solution is one which is neither acid or basic. A solution made with crystal phosphate will be approximately neutral, but it will turn alkaline when used because a slight amount of ammonia gas is set free. The voltage may be regulated by means of resistance in the alternating-current or direct-current circuits. A better means of regulation is that of adjusting the alternating-current voltage by a small transformer with a number of taps. The cell should be artificially cooled to work satisfactorily. L. W. C.

86—INCANDESCENT LAMPS. What are the relative advantages of 16 c-p. incandescent lamps for 110 and 220-volt direct-current service, taking into consideration relative efficiencies, life and first cost? W. O. M.

For 110-volt service 16 c-p. incandescent lamps are made for three standard efficiencies, viz.: 3.1, 3.5 and 4 watts per c-p. The life of these lamps, of course, increases as the efficiency at which they are operated is decreased. Thus the standard lamp at the three efficiencies given would have a useful life of approximately 500, 1 000 and 1 900 hours respectively. A corresponding standard 16 c-p. lamp for 220-volt service to give a useful life equal to that of the corresponding 110-volt lamp operated at a power consumption of 3.1 watts per c-p. must be operated at a power consumption rate of about 3.8 watts per c-p. The list price of the standard 16 c-p., 220-volt lamp is about two cents more than that of the 110-volt lamp.

87—WHAT CHANGES IN DESIGN OF THE POLE PIECES or of the winding of the armature of a direct-current motor or generator are necessary to give a larger neutral point so that under a very shifting load the brushes will always remain on neutral? This is especially interesting in such a case as a shunt motor driving a shaft which distributes power to a large number of small machines (for example, sewing machines) which may all be thrown on or off at any moment. Would the operation of the motor with these conditions be improved by using brushes covering a greater number of bars on the commutator? G. de La R.

This broad neutral may be obtained by proportioning the pole pieces to cover a fair portion, say 75

percent of the armature and by leveling the pole tip to give a fringing out of its magnetic flux. The neutral will shift more or less as the load varies from no-load to full-load, but by keeping the magnetic saturation in the pole tips high, the flat no-voltage portion of the field form may be prevented from shifting to the extent that a brush of the proper thickness will remain in this neutral portion. In cases where sudden changes from no-load to very high overloads are encountered, auxiliary field windings may be used to keep the neutral point from shifting. Midway between the main poles a set of narrow poles is placed, which are wound with wire or strap of sufficient cross-section to carry the maximum current of the motor. This winding is connected permanently in series with the armature and has its number of turns so proportioned that the ratio of auxiliary ampere-turns to armature ampere-turns is somewhat greater than one. The use of auxiliary poles and windings is especially desirable on variable speed motors or variable voltage generators where the variation of speed or voltage is obtained by varying the field strength since in either case the pole tips will necessarily become unsaturated. The operation of the motor would not be improved by the use of thicker brushes unless the brush current density is excessive. See also question and answer No. 13 in the JOURNAL for January. F. A. R.

88—REVERSING THREE-PHASE MOTORS. Can three-phase induction motors have their direction of rotation changed readily by means of a switch at the command of the engineer as is the case with direct-current reversible motors, and what changes in the wiring are necessary to change the direction of rotation? D. B.

Reversal of direction of rotation is easily accomplished by the use of a two-pole, double-throw switch inserted in two of the three phases of the motor, between the starter and motor. The starter thus connected serves to start the motor in either direction, depending on which way the reversing switch is thrown. The effect of reversing two of the three phases is to change the order in which the currents follow one another in the motor windings and accordingly change the direction of rotation of the revolving field. The two motor leads should be connected to the two middle terminals of the switch; the leads running from the switch to the starter being connected to the two outside terminals at one end of the switch, and these being connected to the other two outside terminals by crossed or x-connections. E. E. L.

89—USE OF MOTORS OF DIFFERENT HP ON SAME CAR. Would it be possible to operate motors of different hp on the two trucks of a car with a greater load on one truck than on the other; the idea being that with the lower rated motors on the light loaded truck, a greater draw bar pull could be obtained on account of these motors not slipping as soon as they could, if they were of the same hp? Take, for example, a car having 20 000 lbs. on the four forward wheels and 30 000 on the rear wheels, 40 hp motors being on the forward truck and 60 hp on the rear. If the speed-torque characteristics were similar, would they operate satisfactorily? Also, how should they be connected? H. A. M.

The scheme of using larger motors on the truck that carries the greater weight, in order to secure a greater total tractive effort, is perfectly feasible in the case of four-motor equipments, provided the speed-torque characteristics of the motors are similar. In the case of two-motor equipments, however, the scheme would be impracticable if the series-parallel control were used, for when the motors are connected in series the small motor will develop more tractive effort than the larger one, since the torque per ampere, as a rule, increases as the size of motor decreases. In four-motor equipments each large motor should be permanently connected in parallel with a small one, and the two pairs then be connected either in series or in par-

allel. The motors should be geared so that for any speed of car the tractive effort developed by the motors will be proportional to their horse-power ratings. H. C. K.

90—METHOD OF DETERMINING TRANSFORMER LOSSES. We have two transformers connected in open delta (or V) on a three-phase line, the core loss on each transformer is two kw per hour, the resistance of the primary is three ohms and that of the secondary 0.02 ohm. The average load per hour is 100 kw, 24 hours per day, 30 days per month. The primary voltage is 20 000 volts and the secondary voltage is 2 000 volts. How much loss in kw-hrs. will there be for the 30 days? Will the current be kw÷volts, or will it have to be divided by $\sqrt{3}$ (or 1.732)? Are not all the transformers working as single phase transformers with a third wire for common return? C. W. C.

The current in each transformer= $\frac{\text{kw}}{\text{volts} \times \sqrt{3}}$, that is the current in the transformer is the same as the current in the main. In this case the current in the primary= $\frac{100\ 000}{20\ 000 \times \sqrt{3}}$ =2.89 amperes and in the secondary equals $\frac{100\ 000}{2\ 000 \times \sqrt{3}}$ =28.9 amperes. Then the copper loss per transformer equals $\overline{28.9}^2 \times 0.02 + \overline{2.89}^2 \times 3$ =41.75 watts. (This small loss is out of proportion for a practical transformer.) The total loss for 30 days in kw-hrs. therefore equals 2×(2+0.04175)×24×30=2940 kw-hrs. The transformers are not working as single-phase transformers with a third wire for common return due to the difference in phase of the voltages induced in the transformer secondaries. This is manifested by the resultant voltage between the outside mains, (which is the vector sum of the voltages in the two transformers), being the same as between any other two mains, whereas, in the three-wire single-phase system (since the two voltages are in phase) this resultant or vector sum becomes the algebraic sum or twice the voltage between the other mains. Another point of difference is that the current and voltage in each transformer are 30 degrees apart, while in the three-wire type they would be in phase under similar conditions of load.

A. D. F.

91—CAN A DELTA-CONNECTED TRANSFORMER be half tapped for alternating current starting of motors? H. D.

Yes, this is explained in volume II of the JOURNAL, p. 101. H. C. S.

92—CAN A NEUTRAL CONNECTION be taken off a delta connected transformer? What is the advantage of using a star connection over a delta? H. D.

There are no points which can be selected on the three transformers of a delta-connected set which would always be at the same potential at the same instant and hence there is no natural neutral point. There are two reasons for using star-connected transformers, one being to obtain a natural neutral point and the other to obtain a given voltage relation, the voltage across phases with a star-connected set being 1.73 times the voltage of one transformer. This voltage is obtained with a maximum voltage to ground potential on any transformer equal to the natural voltage of one transformer. Although the potential strain to which the insulation is subjected with a star-connected arrangement is less than that of the delta-connected arrangement the Underwriters require the same test voltage because, in case the ground connection of the neutral becomes disconnected, the insulation is then subjected to the full potential across the phases.

H. C. S.

93—IF A REVERSE CURRENT IS CAUSED TO FLOW THROUGH A COMPOUND DIRECT-CURRENT GENERATOR, WHAT IS THE RESULT? H. D.

The effect of a reversal of current due, for example, to the circuit being accidentally connected to a

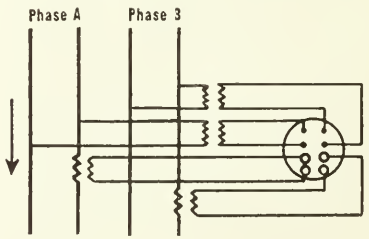
source of power of opposite polarity and of enough higher voltage than that of the generator to overbalance its voltage and thus cause the current to flow in the opposite direction would be to cause the machine to run as a differentially wound motor, continuing to rotate in the same direction as when operating as a generator. The direction of current would, of course, be reversed in the series field, but not in the shunt field. Hence, when the source of trouble was removed the machine would pick up its voltage in the proper direction unless under the abnormal conditions sufficient current was drawn to overbalance the shunt field by the series field. C. F. L.

94—Oil Switches for Low Voltage Direct Current. Are oil switches practicable for making and breaking a 250 or 500 volt direct-current circuit supplying power to a 25 hp motor? I have in mind a motor that must be started and stopped every few minutes, but never saw oil switches for such service advertised. J. H. H.

Oil switches can be used to advantage for 250-500 volt direct-current service. They can be manufactured at a saving in cost over that of air-brake switches for even smaller capacities than this. The saving in cost of construction increases as the capacity increases and they are found to give satisfactory operation on even larger capacity service than that stated above. Standard forms of apparatus for direct-current service are made by some of the well known electrical manufacturing companies and circulars or bulletins describing such apparatus can usually be obtained on application to the manufacturers H. G. M.

95—Reversing Two-Phase Motors. Why will a two-phase motor connected to a three-wire two-phase system reverse its direction of rotation when the two outside leads are changed instead of when one outside lead and the neutral are changed? Why does it not change the two phases? B. L.

In a two-phase, three-wire motor, the middle or common wire delivers the current of both phases to the junction of the two windings on the motor. The current in the middle wire divides at the junction, part going through winding A and part through winding B. In a given case the current in A may cause the first coil in that winding to produce a positive pole a little later than that produced by the current through the first coil of winding B, resulting in rotation in a definite direction. Obviously, if the currents in A and B were interchanged the sequence would be changed and the rotation reversed. The currents may be interchanged by reversing the outside leads, thus causing the current which did flow through A to flow through B and vice versa. It may be noted that the direction of rotation is likewise reversed if the direction of current flowing through one of the windings A or B is reversed. Thus, if in a given case the current through a coil of winding A causes the pole produced by it to follow the pole produced by an adjacent coil in winding B, by a quarter cycle (or 90 degrees) then reversing the connections to winding B will reverse the direction of current in B, so that a pole which had been positive at a given instant will now be negative. The current has been delayed a half cycle (or 180 degrees). A pole of B which preceded a pole of A by 90 degrees now follows it at 90 degrees. The sequence of the poles is changed and the rotation reversed. C. F. S.



CORRECTED CONNECTION DIAGRAM, P. 263, FIG. 6, MAY, '08. "METER AND RELAY CONNECTIONS," BY H. W. BROWN

THE

ELECTRIC JOURNAL

VOL. V. JULY, 1908 NO. 7.

The Analysis of Wave Forms

To the average engineer the value of any method of wave form analysis depends largely upon the simplicity of its application to particular cases. Ordinarily there are so few occasions for the use of such an analysis that the method must be looked up each time, and that method will be most useful which is most readily applied, even though it may involve some additional labor. The method described by Mr. Lincoln in this issue of the JOURNAL is beautifully simple, and when thoroughly understood should enable one to work out an analysis with the minimum amount of labor. The article is worthy of considerable study and for those expecting to use it in practice a few notes indicating the order of application to any particular case will render it very easy for subsequent use.

In an analysis of wave forms one is interested in knowing; first, the value of the maximum ordinate of each harmonic and the fundamental, and second, their phase relation. In the Fischer-Hinnen method described by Mr. Lincoln the value of the maximum ordinate of each harmonic is determined by first obtaining the values of each of any two ordinates of that harmonic, that are ninety degrees of the harmonic circle apart. The square root of the sum of the squares of these two ordinates gives the value sought. This process is repeated for the value of each harmonic investigated. Mr. Lincoln has given the theory of this method together with the corrections that must be used to allow for variations produced by harmonics that are multiples of the one under consideration. Thus for accurate work it is necessary to correct the value obtained for the third harmonic for variations introduced by the ninth, fifteenth, etc. The fact, that practically all waves with which electrical engineers are concerned are symmetrical about the X-axis, makes it unnecessary to solve for the even harmonics.

It should also be noted that when the wave forms are symmetrical about the X-axis, as stated above, and are also symmetrical about their middle ordinate of a half wave, the harmonics all pass through the zero value at the same time as the fundamental wave.

When the phase relations of the harmonics are desired the value of the angle is determined by the relation of the ordinates previously obtained. The angle thus determined will be expressed in degrees of the harmonic circle and must be divided by the number of the harmonic if it is desired to plot it on the original curve. The harmonic can, of course, cross the X-axis either to the right or left of the crossing point of the complex wave. It can be going either upward or downward in each of the two cases. It is, therefore, necessary to locate the crossing point and its direction of crossing. This gives four possible combinations. A little study will indicate the correctness of the following rules for determining which of the four conditions any particular analysis really fills. These positions are ascertained by the signs of the two ordinates determined as follows:

If A is plus and B is plus the harmonic crosses to the left going upward.
If A is minus and B is minus the harmonic crosses to the left going downward.
If A is plus and B is minus the harmonic crosses to the right going downward.
If A is minus and B is plus the harmonic crosses to the left going upward.

It should be borne in mind that these angular determinations are with reference to the zero point of the wave under analysis and not the fundamental. This assumes the division of the half wave from the crossing point as the y_0 value.

If it is necessary to make a complete analysis of a wave and determine each of the harmonics up to the seventeenth or nineteenth, the labor involved in dividing up and making arrangements of a separate set of ordinates for each harmonic may require more labor than the process of analysis employing but one set of ordinates and multiplying them by a table of constants for each harmonic. This last mentioned method is referred to in a foot note of Mr. Lincoln's article. There can be no question, however, but that the Fischer-Hinnen method is the shortest and involves the least labor for any analysis extending not farther than the ninth harmonic.

S. M. Kintner

The Journal Question Box

One of the essential elements in modern progress is freedom of interchange of knowledge and experience. This is particularly true in scientific and engineering progress. It has been one of the characteristic features of the great development and growth which has been made in the electrical industry, particularly during the past ten or twenty years. In taking up a particular line of work an engineer

does not have to start at the beginning, repeating the tedious experiences of others but, profiting by their experience, he can often take up his work where they left off.

If the number of men engaged in a particular line of work is small and they are so associated that they can communicate freely with one another, this interchange of knowledge is a simple matter. When, however, the number is large, and the individuals are widely scattered and the field of work is extended and complex, other methods must be employed. Our principal electrical clearing house is the American Institute of Electrical Engineers. Its transactions are a panorama of electrical progress. While many of its papers present new discoveries and the results of scientific investigation which render the transactions of permanent value, there is another class of papers which discuss methods, which describe difficulties and which are of the highest value, from what might be termed the information and educational standpoint, in assisting and stimulating the great body of electrical workers. The Institute therefore, in its function as a clearing house for the exchange of information and experience has been one of the important factors in bringing about the great advance which has taken place.

The same problem presents itself in an individual organization. When it is small, conferences between engineers and different departments are readily arranged. Young men who enter such an organization are apt to be thrown in more or less intimate contact with those who are advanced in its work. When, however, numbers reach into the hundreds, other methods become necessary. Lecture courses, clubs and the like afford a useful means of accomplishing these objects. The Electric Club was organized five years ago, and it was found after a time that something further was needed; technical papers and discussions should be in permanent form. The outcome of this idea was THE ELECTRIC JOURNAL. Its possibilities for usefulness were found to extend far beyond the limits of a club of a few hundred members and its extensive circulation has shown that the early idea, that there was a large number of engineers who would value this means of interchange of information and experience, was well founded.

Some of the developments have been quite interesting. The contents of the JOURNAL took the form of definite articles, some short, some more extended. These were contributed frequently at the suggestion and request of the editor, and covered a wide field. The formal article, however, was found to have several limitations. It did not readily permit the presentation of many minor matters,

which were not of sufficient importance to justify extended treatment. It did not open up to the reader of the JOURNAL a ready means of making his wants known. The intercourse was all in one direction; it proceeded from the JOURNAL to the reader. The editor and the contributors sought to serve the reader without knowing exactly what was desired and without learning to any large extent whether the articles were acceptable.

To overcome these objections, and introduce a new freedom of intercourse, The Journal Question Box was instituted at the beginning of the present year. It has grown in interest and importance, until it could readily occupy many more pages than can be allotted to it. The questions come from a wide range of sources, geographical and otherwise. A list of the places from which questions have come shows that over half of the states in the Union, as well as several foreign countries, are represented on the list and that only about 25 percent are from Pennsylvania. They come from consulting engineers, editors, professors, managers and superintendents, central station men, students and apprentices. The Editor of the Journal is fortunately situated in that he can conveniently refer these uestions to experts, either for reply or for approval of replies prepared by the staff of the JOURNAL. The situation is, in fact, unique. The technical staff of a large manufacturing company is recognized as being possibly the best source of information regarding apparatus and engineering matters. The relation of the JOURNAL, through The Electric Club, with a group of engineers of this kind, places it in an exceptionally strong position, and one which is not enjoyed by the ordinary technical press. The Question Box therefore gives convenient opportunity for operating and other engineers anywhere to come into fairly direct communication with expert engineers. The initials, following the answers, show that the replies come from many men, a number of whom are quite prominent in their respective lines.

This method of circulating information has developed another interesting point. Engineers, who are too busy to prepare a formal article and who would hardly care to treat a simple point in a formal manner, are quite ready to give an answer to a simple direct question.

In glancing over the Question Box, one is impressed with the character of the questions. In general they deal with real things and not with hypothetical matters which are merely of academic interest. This indicates a healthy condition, in that those who make inquiry are presenting matters which are to them real difficulties, and it

gives interest to those who make reply, as they feel that the information they give is something which will be of real value.

The Journal Question Box has established itself as a useful means of exchange among engineers, and the result of a half year's experience give promise of growing usefulness and value in the future. CHAS. F. SCOTT

Electric Railway Engineering

During 1906 there was published in the JOURNAL a series of articles on "Electric Railway Engineering," which proved of much interest and value to our readers. These articles elicited much favorable comment; in a number of cases they were adopted as a part of the course of instruction in railway engineering for students at prominent technical schools. In this series the general principles relating to the operation of cars and trains were outlined, after which were discussed the various details of motor construction; the methods of control for the operation of cars and trains; the methods of calculating speed-time and power curves, and the effects of changes in operating conditions such as rates of acceleration, lengths of runs, braking rates, line voltage, etc.

These articles were confined entirely to the cars and motors and their operation so that there are a number of sub-divisions of the subject which have not yet been considered. Hence it has been thought advisable to make this series more complete. It is planned to continue these articles through the balance of the present year taking up such subjects as:—the rating and capacity of railway motors; the selection of car equipments; the design of low tension distributing systems, including track, third rail or overhead lines; the use of the train sheet in designing an electric railway; the calculation of trolley and feeder sizes; the selection of contact line; methods of figuring losses; the proper location of sub-stations and the method of determining the capacity and number of units needed; the method of selecting storage batteries for sub-stations; the determination of the size and voltage of high tension lines; the determination of the location and capacity of the power house and the generating voltage; the capacity of generators needed, and the best sizes of units for any given service.

These articles, in connection with the preceding ones, give the proper method to use in designing any direct-current electric railway system, with examples from actual practice. The first article in the second section of this series is given in the present issue by Mr. N. W. Storer.

THE INDUCTION MOTOR—ITS CHARACTERISTICS IN THEIR RELATION TO INDUSTRIAL APPLICATIONS

A. M. DUDLEY

IN discussing the application of any type of electric motor to a given service, it should be borne in mind that there are several questions of broader engineering scope, which must have been carefully considered first. The broadest is the relative advantage of electric drive over other forms of power, both in general, and as modified by peculiar local conditions. Next is the particular form in which the current shall be used; that is, whether direct or alternating. In the present case, it is assumed that for reasons of adaptability, convenience and economy, electric drive is to be installed and is to be applied by means of induction motors. There arise at once two questions in the analysis, one qualitative and one quantitative: first, what type of induction motor shall be employed; second, what shall be the capacity of the units for performing the different operations. It is customary to spend considerably more time in working out the second of these questions than the first. Necessarily each unit, in working under every-day conditions, must be loaded to somewhere near the normal capacity for which it was designed. A load too much in excess of this causes ultimate damage or breakdown of the apparatus, while a load considerably under the normal means that the motor is operating with a performance, both as regards efficiency and power-factor, below that for which it was designed. In this connection, there is a general feeling that it is a common error for the user to install units of too small capacity. from a mistaken idea of economy in reducing the first cost. This feeling is not justified by general experience, for the number of users suffering from a poor power-factor on account of under-loaded motors is quite as great as those who have occasional burn-outs. It is but natural, in the absence of complete data on the amount of power required for the various processes of different industries, that a motor is occasionally over-loaded, or a load is over-motored. These quantitative difficulties are soon discovered and, in general, easily remedied. If, however, the characteristics of a motor, as regards speed and torque, are not quite what they should be, it may discharge its function indifferently for some time and in

the end be pronounced unsatisfactory because of the greater difficulty in analyzing these qualitative elements. "I had a direct-current motor of half the capacity doing this work for years and doing it better," and "my little 25 horse-power steam engine will pull your 50 horse-power motor off its feet," are complaints which the manufacturer of induction motors meets often, and meets successfully by a little elementary knowledge of his motor characteristics, together with some experience in the work performed. It is the province of the designer to calculate a motor for a particular purpose, when the facts of its cycle of operation are presented to him, and the solution of the problem presents no greater difficulty than is usually found in reducing theory to practice. However, when a certain line of motors is once laid out with definite characteristics, it should be possible to take their credentials in the shape of performance curves, and so decide on their eligibility to perform the work desired.

CHARACTERISTIC CURVES

For convenience in consideration, induction motors are first divided according to the structure of the winding in the secondary, into two classes—first, squirrel cage; second, phase-wound. These are again divided into constant speed motors; and variable speed motors. These divisions are made on the basis of the difference in speed-torque characteristics, which is in general the determining feature. Before examining speed-torque curves, there are certain other curves common to all types which should be considered:—

No-load Running Saturation or Excitation Curves—These curves are obtained by running the motor light, that is, entirely free and under no load. If it has a wound secondary, it is run with the secondary short-circuited. The voltage is then varied over a wide range from thirty or forty percent over-voltage down to the lowest voltage at which the machine will continue to run. The ampere and watt input is read for a number of voltages and plotted in form of curves as shown in Fig. 1.

The facts concerning the operation of the motor to be noted from these curves are:—

1—Magnetizing or no-load, wattless current for the air gap alone, (given by the ordinate AB at normal voltage to the tangent drawn from the origin to the ampere curve).

2—Magnetizing current for air gap plus iron, or AC.

3—$AC \div AB$ or saturation factor which indicates the degree of saturation to which the iron is worked.

4—Friction and windage loss, AE.

5—Iron loss, ED. The sum of the two latter losses is called the

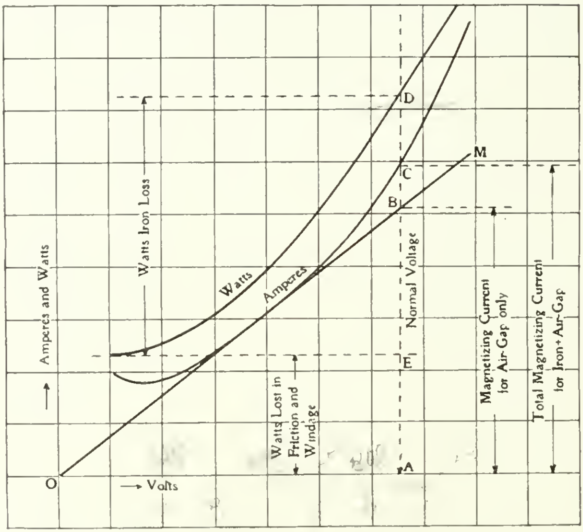


FIG. 1—RUNNING SATURATION OR EXCITATION CURVES OF AN INDUCTION MOTOR

constant losses of the machine as they remain practically the same for all loads, from no-load to fifty percent over-load in distinction from the primary or secondary copper losses, which vary as a function of the load. These curves are useful in giving an idea of the power-factor and efficiency of the machine at different loads. The magnetizing current is the largest component of the wattless current and hence materially affects the power-factor.

The wattless and working current under normal full-load may be represented as two sides of a right triangle (Fig. 2) from which, directly, the full-load power-factor is AO÷AB. As the magnetizing current is constant at all loads and the leakage current varies as a function of the load, it can readily be seen that the magnetizing current affects the power-factor most at light loads, which is another way of saying that a motor with relatively large magnetizing current

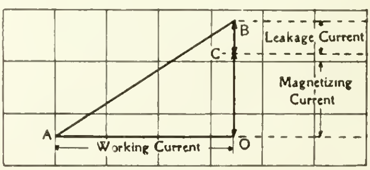


FIG. 2—POWER-FACTOR DIAGRAM

and small leakage current will have a poor power-factor at light loads; or, vice versa, a motor with small magnetizing current and large leakage current will have a good power-factor at light loads. It may also be said, without material error, that large magnetizing current goes with high maximum torque and large leakage current with low maximum torque, which gives again the deduction that a motor which has a high maximum torque will have a poor power-factor at light loads or, conversely, if a good power-factor at light loads is required, it will probably be at the sacrifice of torque.

Locked Saturation or Stationary Impedance Curves—These curves are taken with the motor locked or held at a stand still. As in the case of the no-load running curves the voltage is varied over a considerable range and the watt and ampere input read. It is also customary to put on a brake and read the mechanical torque exerted by the motor. These curves are shown in Fig. 3. As the current at full voltage with the secondary stationary would be excessive, it is customary to take a number of readings at convenient voltages and exterpolate the higher points, remembering that the ampere curve approximates a straight line very closely and the watt and torque curves vary nearly as the square of the voltage. These curves give directly the impedance of the motor and the starting torque at a given voltage; also the current required at start for a given torque. From the watt readings and knowing the resistance of the primary winding, it is possible to figure out the resistance of the secondary in terms of the primary.

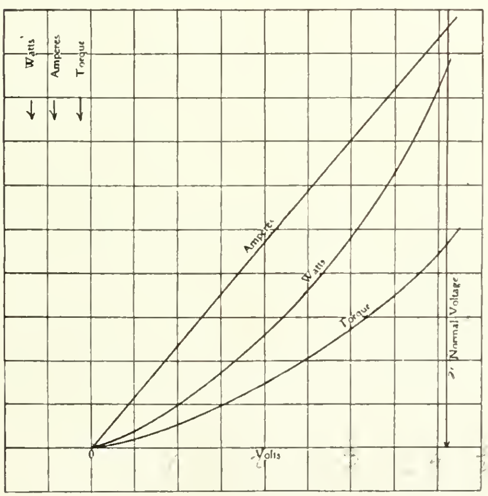


FIG. 3—LOCKED SATURATION OR STATIONARY IMPEDANCE CURVES OF AN INDUCTION MOTOR

Power or Brake Curves—From the no-load and locked readings of current and watts at normal voltage in combination with the primary resistance, there may be plotted, by means of the Heyland

diagram or a similar graphical method, the efficiency, power-factor and speed-torque curves, for any and all loads on the motor, as in Fig. 4. These curves can also be obtained by brake test, reading the speed, torque, current and watt input at normal voltage for several loads. They are most interesting as they tell the complete story of a motor's behavior, with the exception of temperature. After a little familiarity with curves of this nature, it becomes possible to read a number of secondary facts which are of considerable interest and assistance in predicting the success or failure of an application.

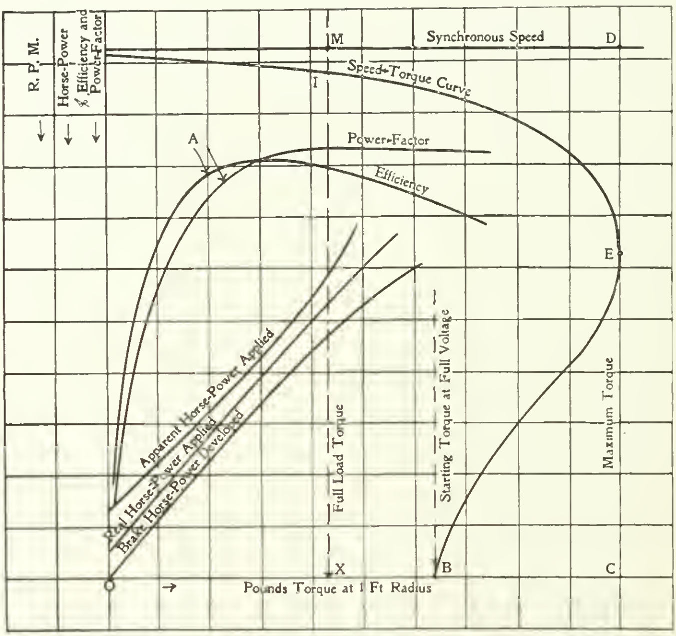


FIG. 4—POWER OR BRAKE CURVES FOR A CONSTANT SPEED INDUCTION MOTOR WITH SQUIRREL CAGE SECONDARY

For example, as pointed out above, if the power-factor curve comes up abruptly and bends sharply as at *A*, the wattless current at light loads is of relatively less importance than at greater loads. Hence the magnetizing current is relatively small compared to the leakage current. This explains the high power-factor at light loads and is a fair prediction that the maximum torque is not excessive. Again, the square shoulder on the efficiency curve indicates low fixed losses as compared to the variable losses. In this connection, it is interesting to note that maximum efficiency occurs at three-fourth load.

This is usually the case in well-designed constant speed motors of moderate capacities and indicates in the design a balance or distribution of the losses to secure the best results in the combination of performance and temperature. The ordinate at any torque to the brake horse-power curve divided by the ordinate to the real horse-power curve is the efficiency at that torque, and the ordinate to the real horse-power curve divided by the ordinate to the apparent horse-power is the power-factor for that torque. Also by the common formula, hp=torque×r.p.m.÷5 250, the horse-power for any torque, such as X, is torque X times speed Y at the same torque divided by 5 250, or Z. The foregoing curves are common to all types of motors and are used for reference on the points not covered by speed-torque curves.

Speed-Torque Curves—In the application of power by means of rotary motion, there are two essential considerations—namely, the torque required, and the speed at which this torque must be developed. There are applications, fairly represented by large rotary printing presses or rolls for calendering paper, where almost a constant torque is required over a wide range of speed. Another class, represented by some machine tools, such as lathes, planers and boring mills, requires a nearly constant horse-power, i. e., the torque increases as the speed decreases. Again, a constant head centrifugal pump motor is called upon to deliver a constant torque at a constant speed. For this reason the characteristic curve which has the most bearing on the application of motors is the speed-torque curve or curves. From this point of view induction motors are divided into four classes, viz., motors with squirrel cage secondary windings for constant speed service; motors with squirrel cage secondary winding for variable speed service; motors with phase-wound secondary for constant speed service, and motors with phase-wound secondary for variable speed service.

The speed-torque curve given in Fig. 4 is characteristic of motors of the first class. Primarily, it is to be noted that the drop in speed from no-load to full-load, or the slip, represented by MI is small. This is described by saying that the motor has good speed regulation or runs at nearly constant speed from no-load to fifty per-cent over-load. Also the starting torque at full voltage or OB in this type is considerably less than the maximum torque OC. In order to have this motor develop full-load torque or OX at the start, it would be necessary, by means of an auto-transformer or compensator, to apply a reduced voltage to the motor in the proportion

(percent of normal voltage applied)^2÷(normal voltage)^2=OX×OB. When a motor of this type, designed with good starting characteristics is developing full-load torque at starting, the primary of the auto-transformer, to which it is connected, will be drawing about three times full-load current from the line. If, however, full voltage be applied directly to the motor and the starting torque OB is one and one-half times normal full-load torque, the motor will draw 3×1.5 or 4.5 times full-load current from the line.

The effect of lowering the resistance in the squirrel cage winding either by increasing the section of the short-circuiting rings at the ends of the bars or by making the rings from a material of lower resistance, would be to decrease the slip or make the point I move

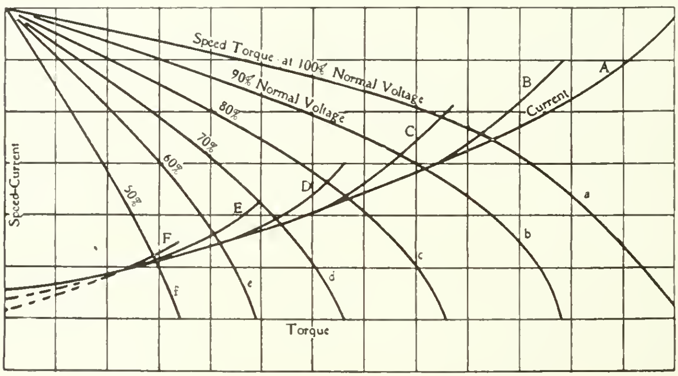


FIG. 5—SPEED-TORQUE AND CURRENT-TORQUE CURVES

For motor with high resistance, squirrel cage secondary winding for variable speed work with voltage control.

towards M, decrease the starting torque at full voltage or cause B to move toward O, and increase the speed at which maximum torque occurs, i. e., cause E to move toward D. All that is said later as to the effect upon the speed-torque curve of changing the resistance in the secondary circuit of a phase-wound rotor is in a degree applicable to a change made in the resistance of a squirrel cage winding.

In motors of the second class the speed variation is obtained by varying the voltage applied to the motor terminals. This is accomplished by means of an auto-transformer with a number of taps on the windings and a suitable controller for applying the different voltages to the motor. The various speed-torque curves for different voltages and also the corresponding current-torques are shown

in Fig. 5. The secondary resistance has been so chosen that maximum torque occurs at starting, or, referring again to Fig. 4, the point *E* has dropped to *C*, becoming one with *B*. This is done for the reason that these motors are, for the most part, used for crane or elevator services or for opening and closing valves, etc., and maximum torque is required at start. The advantages of this type over the variable speed, phase-wound rotor with external resistance are,—simpler rotor construction and simplicity in wiring when used in crane work, that is to say, when the motor is used on the bridge or trolley of a crane it is necessary to run but three trolley wires as against a minimum of five for the phase-wound rotor.

The phase-wound rotor has three advantages, viz:—heat is taken away from the motor and dissipated in external resistance; the controller is more serviceable for the reason that the controller in the squirrel cage motor has to break the circuit in stepping from one voltage to another while in the case of the motor with external resistance the controller merely short-circuits the resistance steps and the chance of burning the controller figures is much less; the motor is quieter in starting, which is a material consideration in the case of elevators in hotels and apartment houses. The process of starting up notch by notch on the controller and moving from one speed curve to the next is practically the same as for the phase-wound rotor and is described in the next class.

The speed-torque curves of the third and fourth class motors may be described together, as they are practically the same, the difference being that the constant speed motor runs with the resistance in the secondary short-circuited the greater part of the time, using the resistance notches in starting only, for the purpose of securing a high starting torque with a moderate current demand from the line. On the other hand, the variable speed motor runs with more or less resistance in circuit, depending on the cycle of operations and the speed desired. With a motor of this type, by properly proportioning the resistance in the rotor circuit, it is possible to obtain full-load torque at starting with very little more than full-load current, perhaps 1.2 times, as against three times pointed out in the case of a direct-current shunt-wound motor with armature resistance control, to secure full-load torque at start with full-load current, but as a matter of fact a little more is required for the reason that there are some secondary losses in an induction motor at standstill which are not present when it is up to speed.

The efficiency, power-factor, and current curves, also the speed-

torque curves for different amounts of resistance of a motor with wound secondary are shown in Fig. 6. The torque is plotted on the horizontal axis and the other quantities against this on the vertical axis. The curves marked *1st Notch* to *6th Notch* are speed-torque curves taken for different resistances and the curves marked *Secondary Short-Circuited* are the full speed curves with all resistance cut out of the secondary circuit. It should be noted in this type of motor that *the power-factor and current are always the*

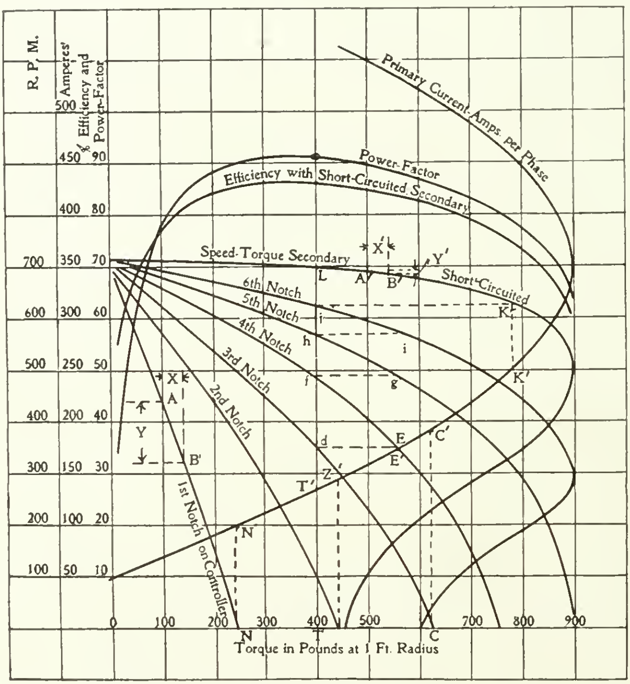


FIG. 6—SPEED-TORQUE, CURRENT, EFFICIENCY AND POWER-FACTOR CURVES

For motor with wound secondary operated with external resistance and controller having seven notches.

same for a given torque, regardless of the speed at which this torque is developed. For example, if the motor is developing 400 lbs. torque, the current required will be T' or 130 amperes, Fig. 6, and the power-factor will be 91.5 percent whether the motor be running at 100 r. p. m. on the 2nd notch, 350 r. p. m. on the 3rd notch, 490 r. p. m. on the 4th notch, 570 r. p. m. on the 5th notch, 625 r. p. m. on the 6th notch, or 700 r. p. m. on the short-circuited curve. This fact,

that the current and power-factor are the same for a given torque at any speed, is a characteristic one for this type of motor and should always be borne in mind. The efficiency, on the other hand, for a given torque varies widely with the speed; as is explained later.

The operation of starting up a motor of this type is as follows: Suppose the start is to be made against a torque of 400 lbs. The controller is thrown to the first notch, putting the full line voltage on the primary terminals of the motor and inserting such an amount of resistance in the secondary circuit that a torque N is developed and a current N' drawn from the line. As this torque is less than 400 lbs., the motor does not start. The controller is moved to notch *2*, giving a torque Z and drawing a current Z' from the line. This torque is slightly in excess of the 400 lbs. required, but owing to the fact that the friction of rest is greater than the running friction, the chances are that the margin is still too small and there is no start. When the controller is put on notch *3*, a torque C is developed and a current C' drawn from the line. The motor starts and accelerates up the curve marked *3rd Notch* until the point d or 350 r. p. m. is reached. Here the torque is just equal to the 400 lbs. required, the current having fallen during the acceleration from C' to T'. The stable condition is at 400 lbs. and the motor runs at 350 r. p. m. until the controller is thrown to the 4th notch, when a torque E is developed and the motor again accelerates along the curve marked *4th Notch,* until the point f or 490 r.p.m is reached, the current having increased from T' to E' and fallen again to T' in the process. Similarly, the controller is thrown to the 5th notch and the motor accelerates from G to H; to the 6th notch, accelerating from I to J; finally all the resistance is cut out and the motor run from K to L, which is full speed, as long as desired. As shown on these curves the resistance is poorly proportioned on the last step, because in throwing from the 6th notch to short-circuit, an excessive torque K is developed, requiring a current K'. This could be considerably reduced by so proportioning the resistance that the 6th notch curve runs closer to the short-circuited curve. This is, in brief, the operation of starting a motor of this type and it appears at once that it is possible to run at any speed at will by merely inserting enough resistance. There are two very serious objections, however, to operating a motor of this type at reduced speed, either of which may be prohibitive for a given application. The first is poor regulation, the second poor efficiency. Poor regulation is most

easily explained by referring again to Fig. 6. Suppose the motor is running on the first notch at the point *A*, or 440 r. p. m.; the load torque increases slightly, say 40 pounds, which is only about ten percent of full-load torque. At once the speed fall nearly 17 percent of synchronous speed to the point *B* or 320 r. p. m. The change in torque is shown as *X* and the change in speed as *Y*. Suppose, instead, the motor had been running on the short-circuit curve at *A'* and the load torque increased ten percent to *B'*. The motor speed in this case falls only about one percent or the amount *Y'*. A comparison of the drop in speed *Y'* with *Y* explains the poor regulation at reduced speeds. This may become very embarrassing at times, as for example,—suppose an operator is threading paper into the rolls of a paper calender. To do this it is necessary to run at about one-tenth the normal speed. He inserts resistance and begins entering the paper between the rolls. The paper runs a little thick for awhile and the increased torque almost stops the calender. The operator then cuts out some resistance and runs at the right speed again. The thick spot passes, the required torque diminishes and the motor increases its speed so suddenly that the paper is broken. A proper study of the conditions of this application should have indicated that the characteristics of this motor made it unfit for this work.

The objection of poor efficiency at reduced speeds is, if possible, more serious than that of poor regulation. It appears most readily from the fact that whenever the motor operates at reduced speed, energy is wasted in heating the external resistance, and, of course, the lower the speed, the poorer the efficiency. If the efficiency curve for a short-circuited secondary is given, as in Fig. 6, suppose it is desired to obtain the efficiency at a torque of 400 lbs. at 350 r. p. m. The efficiency from the curve is 86 percent when the motor is running at *L* or 700 r.p.m. The efficiency at 350 r.p.m. is then, for all practical purposes $\frac{350}{700}$ of 86 percent, or 43 percent, which is so low as to be prohibitive. Another view of this is that while the motor is delivering 400 lbs. at 350 r.p.m., or about 27 hp, it is really developing 54 hp, the remainder being wasted in the resistance. These objections, of poor regulation and efficiency, apply mainly in the case of motors operated a great portion of the time at reduced speeds. They are not at all a serious drawback for intermittent service, such as crane, hoist and elevator work, for which this motor is eminently fitted.

There are several differences between phase-wound secondary motors for constant and variable speed service. The motor for constant speed is designed to run continuously with a good power-factor and efficiency. Its magnetizing current is low, giving the square shoulder to the power-factor curve shown in Fig. 6. The resistance in the starting device is of sufficient capacity only for overcoming heavy torques at the moment of starting or for starting moderate torques with a minimum current demand, as many power companies object to the starting current drawn from the line by some commercial types of motors with squirrel cage secondary construction. The motor for variable speed is designed almost wholly with reference to torque rather than power, its horse-power rating is only nominal, as in the case of direct-current railway or crane motors. In the best designs the magnetizing current is high and the iron worked very hard. This has a tendency to lower the efficiency and power-factor and increase the temperature, but the result is a greatly increased torque, which is the object sought for. A motor of this class should always be chosen with a maximum torque capacity at least twice the nominal rating necessary for the work in hand.

TYPICAL APPLICATIONS

No attempt will be made under this heading to make a complete list of all the uses to which induction motors are put or to give in detail the capacities required. This is data which is rapidly accumulated in practice and which most of the larger manufacturing companies will supply on request. There are, however, some fundamental facts, the observance of which makes application easier and there are occasional points of interest in unfamiliar operations of machines which are worthy of notice. The list given in Table I and the following comments are submitted with this intent:

Squirrel Cage Motors for Constant Speed Service—Motor-Generator Sets—Of all applications of constant speed motors the most typical is its use on motor-generator sets. Small starting torque is required and good speed regulation, which characteristics are pre-eminently met by a squirrel cage motor with very low resistance in the secondary rings. This resistance might be lowered indefinitely, thereby reducing the slip and improving the regulation, if it were not necessary to secure sufficient torque to start the set with reasonable starting current. A fair specification on a large set is that it shall start on thirty to forty percent of full voltage, and draw current not in excess of one and one-fourth times full-load current.

TABLE I—INDUCTION MOTOR APPLICATIONS

Squirrel Cage		Phase-Wound	
Constant Speed	Variable Speed	Constant Speed	Variable Speed
1—Motor-generator sets	1—Starting motors	1—Flour mills	1—Hoists and winches
2—Pumps:— Centrifugal Plunger	2—Crane motors	2—Paper machinery:— Pulp grinders Beaters	2—Cranes
3—Blowers:— Fans Positive Blowers	3—Fly-wheel service:— Punches Shears Hoist motor-generator sets	3—Belt conveyors	3—Elevators
4—Line shaft drive	4—Sugar centrifugals	4—Wood planers	4—Fly-wheel motor-generator sets
5—Cement machinery:— Grinders Kilns Tube and ball mills	5—Laundry extractors	5—Air compressors	5—Steel mill machinery:— Charging machines Skip hoist
6—Wood working machinery (except planers)	6—Brake motors	6—Line shafting	6—Coal and ore unloaders
7—Cotton mill machinery:— a. Group drive b. Individual drive Looms Spinning frames Warpers Twisters	7—Cross-head motors	7—Driving wheel lathes	7—Dredging machinery
8—Paper machinery:— Calendars Paper machines Jordan engines	8—Valve motors		8—Shovels
9—Concrete mixers			9—Mine haulage

Pumps—A fact always to be borne in mind when using a constant speed motor, either alternating-current or direct-current, with a centrifugal pump is that *decreasing the head pumped against increases the load on the motor.* This seems paradoxical, but many motors have been burned out because the user calculated that if a motor would pump a certain quantity of water against a 40 foot head, it would have less load at a 30 foot head. As a matter of fact, the design of this type of pump is such that it will raise considerably more than four-thirds the amount of water 30 feet that it did 40 feet, with the result that the motor is overloaded. In this the centrifugal pump is exactly opposite to the plunger or reciprocating pump, which, being positive in its action, increases its load with increase of head and vice versa. A great many centrifugal pumps have little overload capacity and beyond that point the load to drive them decreases. This is sometimes useful in figuring an installation of this kind, as pump manufacturers can always supply information regarding the pump characteristics.

Blowers—Rotary blowers, except positive blowers, have a characteristic similar to centrifugal pumps, in that the load varies with the amount of air delivered and becomes less as the pressure against which the blower is working increases. That is to say, the maximum load which could be put on a motor driving a blower of this nature would be to take away all delivery pipes and let the blower exhaust into the open air.

Line Shafting—Squirrel cage motors are used very successfully for driving line shafting where the idle belts are run on loose pulleys, in this way keeping down the starting toque.

Cement Mills—The use of induction motors in cement mills has increased tremendously in the past five years and they have many points to commend them for this service. This application is typical of many where the atmosphere surrounding the motor is continuously filled with foreign matter, which is drawn into the motor and is apt to interfere with its operation. The possibility of entirely covering the bearings and the absence of all moving contacts make the squirrel cage motor successful where the more complicated construction and moving contact surfaces of the wound secondary motor or the direct-current machine are damaged by accumulation of dust. Perhaps the most typical apparatus in the cement plant is the tube mill. This is a hollow cylinder about twenty-two feet long and five to six feet in diameter, mounted horizontally. This is loaded one-third to one-half full of flint pebbles about two or three inches

in diameter. The cylinder is rotated and the cement clinker, already in a fairly fine state is fed in at one end and passed through to the other by a screw action inside the mill. The abrasion of the pebbles upon one another and upon the clinker reduces it to the condition of commercial cement. In starting up the mill it must be rotated through nearly ninety degrees before the charge of pebbles and cement begins to roll. This makes the starting condition severe and a motor should not have a starting torque of less than twice full-load torque to do the work.

Wood-working Machinery—Almost all wood-working machinery can be driven successfully by this type of motor, with the possible exception of some heavy planers. On account of high friction and great inertia, the starting torque is sometimes so high and of so long duration (thirty seconds to one minute) that it is better to apply a wound-secondary motor.

Paper Machinery—Under paper machinery mention is made of calenders. If they are driven with a constant speed motor it is necessary to make some provision either by mechanical speed changing devices or a small auxiliary motor for securing a slow threading speed. A somewhat similar problem is presented in the operation of large rotary printing presses. An unusual or "freak" application in paper manufacture is one in connection with a "Jordan engine." This is a machine used in the reduction of wood fiber to pulp, in which the material is forced between a conical plug and a conical shell surrounding it. The material of this plug wears, and in order to preserve the proper working space between plug and shell, the entire rotating part with the driving shaft must be moved parallel to the shaft. Owing to the construction of the Jordan engine, the entire driving motor cannot be moved relative to it, so that the motor is built with an end play of six inches, i. e., the rotor iron in the core is six inches wider than the stator iron and the bearings are so arranged that the entire rotor can move endwise six inches without otherwise interfering with the operation.

Squirrel Cage Variable Speed Motors—These motors in general have high resistance end rings, high slip and high starting torque. The torque increases automatically as the speed decreases. In these general respects they resemble a direct-current series motor and are in fact fitted for the same class of work, with the added advantage that they have a limiting speed and cannot run away under light load.

Starting Motors—The most special application and yet the most common is in starting rotary converters or synchronous motors. If,

for example, the rotary converter has ten poles, the starting motor is built with eight so that when up to speed the starting motor will carry the rotary somewhat above synchronism. When the field is put on the rotary the added load on the starting motor, due to iron loss and field copper loss, is just sufficient to pull the speed down to synchronism. It is a most interesting and rather difficult problem in design so to arrange the starting motor that it will have sufficient torque to start the synchronous machine from rest and still have exactly the right torque at synchronous speed to take care of the losses on the synchronous machine. These motors are very successfully used on cranes for operating the trolley bridge and hoist.

Fly-Wheel Service—Another wide application is that of driving tools which are used with fly wheels, such as punches, shears, straightening rolls and the like. It is here that the usefulness of high slip comes in, as if the fly-wheel is to give up its energy, it is obliged to slow down in speed when the load comes on. A motor with good regulation and low slip would try to run at constant speed, carrying the fly-wheel and load as well, but the motor in question "lies down" and allows the fly-wheel to carry the peak load, speeding up again when the peak has passed.

The application to fly-wheel motor-generator sets for hoisting is the same as that described later under wound-secondary motors.

Centrifugals—In sugar centrifugals is an application where the sole purpose of the motor is to accelerate the load to full-speed, in say thirty seconds, where it is allowed to run one minute and then shut down to repeat the cycle a minute later. The centrifugal consists of a cylindrical basket with perforated walls and mounted around a vertical shaft as an axis. A charge of wet syrupy sugar is placed in the basket and the motor spins it up to a high speed, throwing the mass out against the basket, where the syrup is expelled through the holes by centrifugal force, leaving the dried and refined sugar in the basket. Not the least curious fact about this application is that the center of gyration changes when the mass of sugar flies out against the basket and the center of gyration may or may not be in the shaft. The latter fact makes it necessary to have the shaft flexibly connected so that it may follow the gyroscopic action of the mass. Also the grain of the sugar is affected by the rate of acceleration, certainly a very close relation between speed-torque characteristic and product. The same principle is used in laundry extractors where the wet linen is placed in a similarly perforated basket and the water whirled out by centrifugal force.

Torque Motors—This type is often used to apply brakes, to move the cross-heads of heavy machine tools or to open or close heavy valves. In this service they are called "torque motors" for the reason that they work but a few revolutions and come to rest again.

Constant Speed Motors with Phase-Wound Secondaries—There are classes of service which require a heavy starting torque combined with close speed regulation after the motor is up to speed. These requirements are exactly met by a motor with a phase-wound secondary. The secondary winding itself has a very low resistance, which means a small "slip," high running efficiency and power-factor and good regulation when the secondary is short-circuited, as explained above. It would also mean poor starting torque and high starting current if of the squirrel cage construction, but the insertion of external resistance enables the motor to develop maximum torque at the start with a moderate starting current. In this way these apparently contradictory requirements are most satisfactorily met.

Flour Mills—The number of line shafts, belts and gears in flour mills makes a very heavy starting condition and the nature of the product and its quality demand absolute speed within a few revolutions per minute. The best solution is the phase-wound rotor.

Other Examples—There is another class of machinery which is not so exacting about regulation but which has the same feature of heavy starting and runs continuously after once up to speed. Under this head come most of the applications of this type of motor. They are, paper pulp grinders, which, on account of the inertia of the grindstones, are hard to start; pulp beaters which stir up the pulp in process of manufacture and which start hard because the pulp settles nearly solid around the moving parts when the machine is at rest,—belt conveyors, which may be required to start when full of coal, crushed rock or cement; air compressors, which have a high starting friction because of the construction and the number of parts; line shafting where the belts run for the most part on the working pulleys and are therefore heavy to start. Under the best possible conditions, if line shafting is employed, the loss of power from this source alone, due to friction is twenty-five to thirty percent and may easily run up to forty or fifty percent. This is a strong argument for individual drive of machines wherever practicable.

Driving Wheel Lathe—It has been stated that this type is not fitted in general for individual drive on machine tools, but there is one interesting case where such an application is made successfully.

In turning up driving wheels of locomotives a special lathe is used. As the diameter is nearly always the same and this lathe handles only one job, the speed is practically constant. It so happens that occasionally there is a hard spot in the steel over a considerable arc of the circumference and if the entire cut is made at one speed, the tool is damaged by this hard spot. On account of the large cutting diameter the speed is small so that if provided with a motor of the type in question the operator can throw in resistance enough to reduce the speed about fifteen percent while cutting the hard spot and throw it out again so as to cut the remainder of the revolution at full-speed. In practice, when the hard spot is discovered, the operator marks that portion with a chalk mark and slows down the lathe each revolution when this section approaches the tool.

Motors with Phase-wound Secondaries for Variable Speed Service—The application, which is typical of this class, is found in hoist and crane service. Motors for this work are designed for intermittent operation and given a nominal rating based upon the horse-power which they will develop for one-half hour with a temperature rise of 40 degrees C. They never operate for as long a period as thirty minutes continuously and they are called upon at times to develop a torque greatly in excess of their nominal rating. For these reasons motors of this class should never be applied on a horse-power basis, but always on a torque basis. Since torque is the main consideration and the service is intermittent these motors are usually wound for the maximum torque which they will develop and given a nominal rating based upon one-third to one-half of this torque. The frame will carry this for thirty minutes with a safe rise in temperature and there is a margin of two to three times the rated torque, which in general is sufficient to take care of the peak demand. In case there is a variable cycle to be performed and it is known how many seconds are required for each operation and what torque is necessary, it is customary to calculate the square root of the mean square current for the whole cycle and select the proper capacity on this basis. For all elevator, winch, contractor, skip or single scrum hoist work, a motor, which will develop the power required and carry the equivalent square root of the mean square current for one-half hour with a safe temperature rise, and which has a maximum torque equal to or greater than the maximum torque required by any part of the cycle, will be satisfactory. Double drum hoists, hoisting in balance, and large mine haulage propositions in general require a motor rated on a different basis. For this service the motor should

have the necessary maximum torque and be able to develop for about two or three hours, with a safe rise in temperature, a horse-power equivalent to the square root of the mean square requirement of the hoisting cycle. These are only general rules and the most careful consideration should be given in each individual case to secure a motor which will perform the work satisfactorily.

In consequence of being wound for a high torque these motors have a high magnetizing current and consequently a lower power-factor at light loads than a continuous-rated motor on the same frame would have. The reasons for this can be seen by referring again to Figs. 1 and 2 and the discussion of these curves.

Turntable Donkeys—An interesting application of this type is that of the operation of turntables at round houses and railroad shops, for turning locomotives. There is usually a carriage provided for the motor called a "tractor," or a "donkey," which runs on the same rail as the turntable to which it is secured. The current is carried into the motor through collector rings on the center pin on which the table turns, or in some similar way by the use of moving contacts.

Coal and Ore Unloading Machinery—Dredges-Power Shovels—In apparatus of this type there are usually several motions. There is a bucket or shovel of the clam-shell or similar type, which is lowered into the material to be moved, closed, hoisted, swung around and dumped. The hoisting apparatus in itself is very ingenious and two or three of these motions may be taken care of in some cases by one motor. In other cases there are separate motors for each motion. Owing to the complication of the cycle of operation there is more difficulty in providing a motor for this apparatus than in the case of a plain hoist. Usually the number of cycles per hour given is the maximum which the apparatus can develop and in practice it will not be possible to operate at so high a speed. This in itself is somewhat of a factor of safety, though not one which can be relied upon, as the test for acceptance is ordinarily made at the contract number of operations per hour.

The most impressive application of motors of this class and perhaps in the operation of any electrical apparatus is the fly-wheel motor-generator set for hoisting or heavy reversing roll service in steel mills. Service of this nature is extremely fluctuating in its requirements, having very great peaks one instant and almost nothing the next. This is a severe strain on the generating plant from which power is being drawn and, as power is often charged for on the basis

of the peak requirement, it is evidently a great advantage to apply some device in the nature of a fly-wheel which will smooth off these peaks. A mechanical fly-wheel on the hoist or roll itself is impossible because they are obliged to reverse. The same result is accomplished in the following manner: On the hoist or roll is a direct-current motor having its armature electrically connected to the armature of a generator which drives it, and having its fields separately excited. The driving generator also has its fields separately excited and is part of a direct-connected, three unit set, the other two units being a wound-secondary induction motor and a heavy fly-wheel. Assuming the case of a hoist, the heavy demand comes when the hoist motor accelerates the load. This peak comes back to the generator and through it to the induction motor. As soon as the induction motor begins to draw increased current through its primary from the line, resistance is cut into the secondary circuit by series relays in the primary circuit. As has been shown, the effect of this resistance would be to decrease the speed of the motor-generator set, but before this can happen the fly-wheel must give up part of its stored energy, thus supplying the peak. When the load is accelerated the demand falls and the relay again automatically short-circuits the secondary resistance and allows the motor-generator set to come gradually up to full speed again. The operator has only to control the generator shunt field by a small master controller by which he can reduce this to zero or build it up in either direction, thereby stopping or reversing the hoist motor at will. The motor-generator set runs continuously with its automatic regulation and the reversing motor of thousands of horse-power is started, stopped and reversed in five or six seconds, by a turn of the hand, without the least shock either on the driven machine or the generating system.

WAVE FORM ANALYSIS

P. M. LINCOLN

DURING the last few months the writer has had occasion to resolve a number of alternating wave forms into their simple harmonic components. The only available method, described in the English language, involved as one step of the resolution the process of multiplying together a number of pairs of values,* the number of pairs used depending upon the accuracy desired. At its best this method is long and tedious,, particularly if one is confronted with the position of resolving quite a number of complex curves into their simple harmonic components. An examination of the literature on this subject disclosed an article by J. Fischer-Hinnen, published in the *Elektrotechnische Zeitschrift* of May 9th, 1901. The method described in this article does not seem to

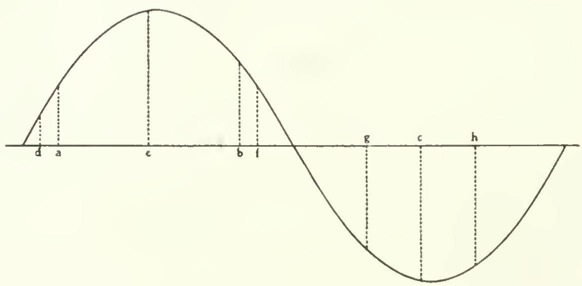


FIG. 1

have been published in the English language. Compared with all other methods of resolving complex waves into their components, this Fischer-Hinnen method is extremely short and accurate, and for this reason the following resume and adaptation of this method is given.

The theory upon which the method rests may be briefly outlined as follows:

Assume a sine wave as shown in Fig. 1. If, in this wave, three ordinates, *a*, *b*, and *c*, are erected 120 degrees apart, the algebraic sum of these ordinates is zero, provided the wave is a perfect sine wave. The same is true for five ordinates, *d*, *e*, *f*, *g* and *h*, provided the interval between them is 72 degrees. In a similar manner the

*This method was described in an article by Mr. A. G. Grier in the Journal for April, 1907. A similar method, described in the *Electrical World* of May 28, 1904, by Mr. S. M. Kintner, reduces the labor involved in applying this particular method to its lowest terms.

same is true for n ordinates, provided the distance between them is $2\pi \div n$, measured in radians.

If a third harmonic wave is superimposed upon a sine wave as in Fig. 2, the algebraic sum of three ordinates—as a', b' and c'—taken 120 degrees apart is no longer zero, and an inspection of Fig. 2 will show that the algebraic sum of these three ordinates is equal to three times one of the ordinates of the third harmonic. One ordinate of the third harmonic can therefore be obtained by taking one-third of the algebraic sum of three ordinates spaced 120 degrees apart. Also if the third harmonic be replaced by a fifth harmonic, one of its ordinates can be obtained by taking the algebraic sum of five ordinates spaced 72 degrees apart and dividing this sum by five. Similarly an ordinate of any harmonic,—for instance, the nth,—can be determined by adding together n ordinates spaced apart a distance of $2\pi \div n$ and dividing the result by n.

It is also subject to proof that the value of an ordinate of any

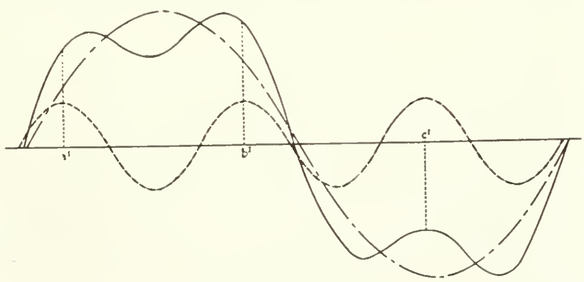


FIG. 2

harmonic as determined in this way, is not affected by the presence of any other harmonic, unless the other harmonic is a multiple of the one being determined. A method of correcting for the influence of these multiples will be shown later.

In electrical work, practically the only curves which engineers are called upon to analyze are those in which odd harmonics only appear. In the ordinary electrical machine no even harmonics are present. The following discussion, therefore, will be restricted to cases in which odd harmonics appear. The method in general, however, is applicable to curves in which even harmonics also appear.

The method consists in determining the value of two ordinates of the harmonic 90 degrees apart. The complete curve is thereby determined. As indicated above, to determine the nth harmonic the base of the half wave should be divided into $2n$ equal parts, ($2n$ parts because only a half wave or 180 degrees of the complete curve

is being used) one of these parts beginning with and one ending with the point where the curve to be analyzed passes through the base line. Let y_1, y_2, y_3, etc., be the values of the ordinates erected at the division points, then:—

$$A_n = \frac{1}{n}\left(y_4 + y_8 + y_{12} + \text{- - -} y_{2n-2} - y_2 - y_6 - y_{10} \text{- - - -} y_{2n-4}\right) \qquad (1)$$

$$B_n = \frac{1}{n}\left(y_1 + y_5 + y_9 + \text{- - -} y_{2n-1} - y_3 - y_7 - y_{11} \text{- - - -} y_{2n-3}\right) \qquad (2)$$

In using these formulæ no values of y of a higher order than y_{2n-1} enter. It is evident therefore that the third harmonic can be determined by measuring five ordinates; the fifth by measuring nine ordinates; the seventh, thirteen, etc.

In the above equations A_n and B_n are values of ordinates of the nth harmonic lying 90 degrees apart. It follows therefore that: O=maximum ordinate of nth harmonic$=\sqrt{A_n^2+B_n^2}$. Since A_n, as determined above, is the ordinate of the nth harmonic at the point

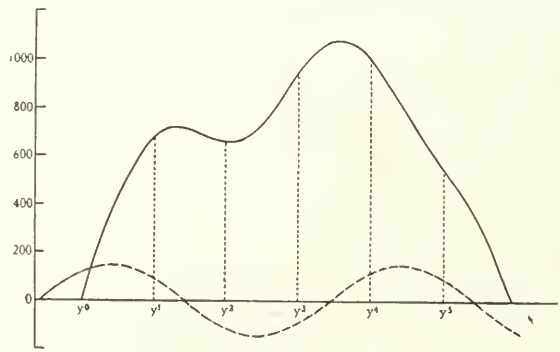


FIG. 3

y_0, or where the original curve crosses the base line and B is the ordinate 90 degrees (in angular terms of the nth harmonic), from y_0, it is evident, that if θ_n, represents the angle between the points where the original curve and the nth harmonic pass through the base line the following relation will exist, $\tan^{-1}\theta_n = -\frac{A_n}{B_n}$ (3)

In this equation Θ_n is the angle (in terms of the nth harmonic) between the point y_0 and the *nearest* intersection of the nth harmonic with the base line. Angular direction from y_0 toward y_1 (or toward the right) is positive and the opposite (or toward the left) is negative; hence, when Θ_n is positive, the nearest intersection of the nth harmonic is to the right of y_0 and when negative, to the left. Further, when B_n is positive, the direction taken by the nth harmonic at its nearest intersection is positive (or upward) and when

B_n is negative, the direction is negative (or downward). For instance in the example given later and shown in Figs. 3 and 4, Θ_3 is negative and the nearest intersection of the third harmonic is to the left of y_0 (Fig. 3). In the same case B_3 is positive and the direction taken by the third harmonic is upward. Referring to Fig. 4, Θ_5 is positive and the nearest intersection of the 5th harmonic is to the right of y_0 (Fig. 4). B_5 is also positive, thus showing that the nearest intersection is in an upward direction.

In some cases it may be more convenient to determine ordinates of the curve being analyzed at equidistant points in the base line, the beginning and end of whose equal sections do not coincide with the points where the curve cuts the base line; for instance, in case a series of ordinates is assumed representing the curve to be analyzed, which values are spaced at equal angular distances along the base line, but whose terminal values are not zero. To apply the above method lit-

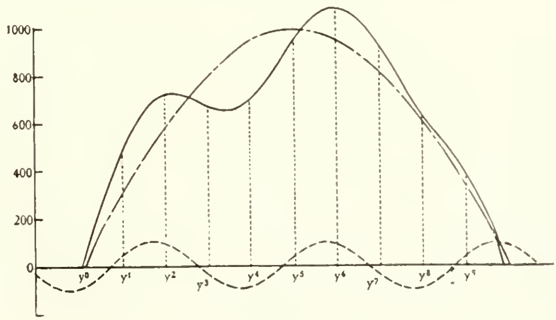


FIG. 4

erally it would be necessary to plot out the curve and determine the ordinates at another series of points which begins and ends with those points where the curve crosses the base line. This, however, is not necessary. If y_0 is taken as the first of $2n$ equally spaced points (n being the harmonic to be determined) the only change in the above formulæ is in the determination of A_n which becomes,—

$$A_n = \frac{1}{n}\left(y_0 + y_4 + y_8 + \cdots y_{2n-2} - y_2 - y_6 - \cdots y_{2n-4}\right) \qquad (4)$$

In other words y_0 is no longer zero, as assumed previously. The datum point for the angular displacements of the harmonics becomes the point y_0, not the point where the original curve cuts the base line. An example will be given later.

The value of harmonics when determined in the above manner are affected by multiples of the harmonic so determined; in other

words, in order to obtain the true value of the nth harmonic, a correction must be applied which depends upon the $(3n)$th, $(5n)$th, $(7n)$th, etc., harmonics. The $(2n)$th, $(4n)$th, etc., harmonics do not appear in this connection since a wave with no even harmonics has been assumed. For instance, the third harmonic must have a correction applied, the amount of which depends upon harmonics of the ninth, fifteenth, twenty-first order, etc., the fifth will be affected by the fifteenth, twenty-fifth, etc. Since harmonics of a higher order than the eleventh rarely enter to an appreciable extent, the application of this correction is not of such importance as might at first appear. If the true values of the A and B components of the nth harmonic are designated as A'_n and B'_n, the corrections to be applied may be determined as follows:—

$$A'_n = A_n - A'_{3n} - A'_{5n} - A'_{7n} - - - - \qquad (5)$$

and

$$B'_n = B_n + B_{3n} - B_{5n} + B_{7n} - - - - \qquad (6)$$

The correction is applied to the determination of the angular. position of the harmonic as follows:

If Θ'_n be the true value of the angular displacement between y_0 and the intersection of the nth harmonic, $\tan^{-1}\Theta'_n = -\frac{A'_n}{B'_n}$. (7)

As indicated above, it is very rare that any correction is necessary in practice beyond that of the ninth harmonic upon the third.

If the curve to be analyzed is symmetrical about its mid-ordinate the analysis becomes very greatly simplified. Such symmetry (even harmonics not appearing) means that all harmonics pass through the base line at the same point as the fundamental and, therefore, as the analyzed curve. All A values therefore, disappear, since $A_n = 0$ in every case. It is unnecessary therefore to use any of the values of y of an even order, such as y_2, y_4, etc.

The determination of the B values also becomes very much simplified. With a symmetrical curve, the following relation of ordinates is evident. $y_1 = y_{2n-1}$; $y_3 = y_{2n-3}$ etc. In other words ordinates an equal distance from each end of the half wave are equal. Therefore, the equation to determine B becomes simplified to the following:—

$$B_n = \frac{1}{n}\left(2y_1 - 2y_3 + 2y_5 - 2y_7 + 2y_9 - - - - y_n\right) \qquad (8)$$

Of course, no values of y of a higher order than y_n are used. With a symmetrical curve, therefore, it is evident that the third har-

monic can be determined by measuring two ordinates; the fifth by measuring three ordinates; the seventh, four, etc.

An example of the method of finding the third and fifth harmonics of a given curve is as follows: Referring first to the curve shown in Fig. 3, measurement shows that the values of the five ordinates spaced thirty degrees apart shown therein are as follows:—

$$y_1=676;\quad y_2=660;\quad y_3=940;\quad y_4=1\,004;\quad y_5=554.$$

By applying the formulae, (1) and (2) already given, it will be found that $A_3=\frac{1004-660}{3}=+114.7$

$$B_3=\frac{676+554-940}{3}=+96.7.$$

O_3=Max. ordinate of third harmonic

$$=\sqrt{A^2{}_3+B^2{}_3}=150.$$

$$\tan^{-1}\Theta_3=\tan^{-1}\frac{114.7}{96.7}=\tan^{-1}1.196=-50 \text{ degrees approx.}$$

This determines the third harmonic both in amplitude and position, and the curve can be drawn as in Fig. 3.

Referring to Fig. 4 (showing the same curve as Fig. 3) measurement shows that the values of nine ordinates spaced 18 degrees apart are as follows:

$$y_1=470;\quad y_2=719;\quad y_3=678;\quad y_4=702;\quad y_5=940;\quad y_6=1\,086;$$
$$y_7=920;\quad y_8=639;\quad y_9=375.$$

From this, $A_5=\frac{702+639\ \ 719-1\,086}{5}=-92.8.$

$$B_5=\frac{470+940+375-678-920}{5}=+37.4.$$

O_5=maximum ordinate of fifth harmonic$=\sqrt{A^2{}_5+B^2{}_5}=100.$

$$\tan^{-1}\Theta_5=\tan^{-1}-\frac{-92.8}{37.4}=\tan^{-1}2.481=68 \text{ degrees approx.}$$

Thus the fifth harmonic is determined both in amplitude and position. In determining the angular position of the harmonics it must be remembered that the results are obtained in angular values of the harmonic sought. Thus the 68 degrees determined for the angular displacement of the fifth harmonic is in angular terms of the fifth harmonic. To reduce this to angular terms of the original curve the values must be divided by five. The curves shown in Figs. 3 and 4 have no harmonics higher than the fifth and therefore no corrections are necessary.

If instead of a curve, a series of ordinate values are given the process would be as follows: Suppose the following figures represent ten values of a half wave, 36 degrees apart:

$y_0=81$; $y_1=250$; $y_2=507$; $y_3=868$; $y_4=1\,032$; $y_5=941$; $y_6=870$; $y_7=868$; $y_8=669$; $y_9=250$. These ten values may be designated as y_0, y_1, etc., as indicated. From the formula (4) given above:

$$A_5 = \frac{81+1\,032+669-507-870}{5} = +81.$$

$$B_5 = \frac{250+941+250-868-868}{5} = -59.$$

Maximum ordinate of the fifth harmonic $= \sqrt{81^2+59^2} = 100$. Angular position of the fifth harmonic $= \tan^{-1}\Theta_5 = \tan^{-1} - \frac{81}{-59} = \tan^{-1} 1.37 = 54$ degrees. That is the fifth harmonic cuts the base line 54 degrees (in terms of fifth harmonic) from the point y_0.

The process of determining the fundamental harmonic, to which the higher harmonics must be added in order to produce the original curve, is similar to that given above for correcting any harmonic curve for higher harmonic multiples thereof. Thus let A'_1 be the *true value* of the fundamental harmonic at the point y_0, then,

$$A'_1=A_1-A'_3-A'_5-A'_7 ---- \tag{9}$$

in which A_1 is the value of the original curve at the point y_0. As indicated in the foregoing, the point y_0 is usually so chosen that $A_1=0$. In using formula (9) care must be used to see that A'_3, A'_5, etc., are given their proper signs . If B'_1 be the *true value* of the fundamental harmonic at the point y_n, (n being the order of the harmonic being determined), then,

$$B'_1=B_1+B'_3-B'_5+B'_7-B'_9- - - - \tag{10}$$

in which B_1 is the value of the original curve at the point y_n. If y_0 is chosen as the point where the original curve intersects the base line, B_1 is its mid-ordinate. It may be noted that the ordinate y_n is always 90 degrees (measured in terms of the original curve) from the point y_0. It should be noted in formulae (9) and (10) that the corrected values of the higher harmonics should be used in obtaining the true value of the fundamental harmonic. Throughout this discussion the corrected values are distinguished by accenting their designations as A' and B'. This is in distinction to A and B which are used to designate the values before correction. The method by which the maximum ordinate of the fundamental and its angular displacement from the original curve are indicated with sufficient clearness in the foregoing.

For mathematical proof of the various steps in the foregoing, the original article by Mr. Fischer-Hinnen may be consulted.

ELECTRIC RAILWAY ENGINEERING—VI

THE CAPACITY AND RATING OF RAILWAY MOTORS*

N. W. STORER

THE function of ratings or statements of capacity of railway motors is to convey information to those immediately interested, which will make possible the selection of the proper motor for a given service without the aid of costly experiments. The limit to the capacity of railway motors is almost invariably due to the rise in the temperature of the coils, so that it is especially necessary that the rating shall give the heating limits in a way that may be applied directly to the service conditions. A horse-power rating, like the rating of stationary motors and generators, gives a general idea as to the commutating limits and the mechanical strength of the motor, but, unlike the rating for generators which is based on their continuous output with a certain rise in temperature, it is usually based on a test of one hour at a load that will give a rise in temperature of 75 degrees C. It can thus give no definite idea as to the average load the motor can carry or the average amount of heat it can dissipate, and really represents the heating conditions of absolutely no existing class of service. It is therefore necessary to have further information than the result of such a test in order to select motors intelligently, especially for suburban, interurban and elevated railways.

The rational way to decide what further information is necessary is to analyze the actual work the motor has to do, to locate and determine the amount of loss it sustains in service, and then to find what shop test can be made that will reproduce the losses and other important conditions of such service. This involves:—

1—A definite knowledge of the service for which the motor is to be used, including the schedule speed, the profile and alignment of the road or a statement as to its grades, curves, etc., the number of stops and the accurate weights of cars loaded and unloaded.

2—A knowledge of the characteristics of the motor, including speed, tractive effort, resistance of windings, and the iron losses at the various voltages.

With this information at hand a set of curves may be drawn that will show very closely the variations in load and speed of the motor

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* A revision of an article published in the Street Railway Journal of Jan. 5, 1901. Revised by the author for *The Electric Journal.*

throughout the different cycles of work it will have to perform. From these load curves the losses in the motor may be calculated.

In order to properly illustrate the method of doing this, a practical example is given. The assumptions in regard to operating conditions in the case are as follows:

Track—level.
Schedule speed—24 miles per hour.
Weight of car with equipment and load—40 tons. (4-75 hp motors)

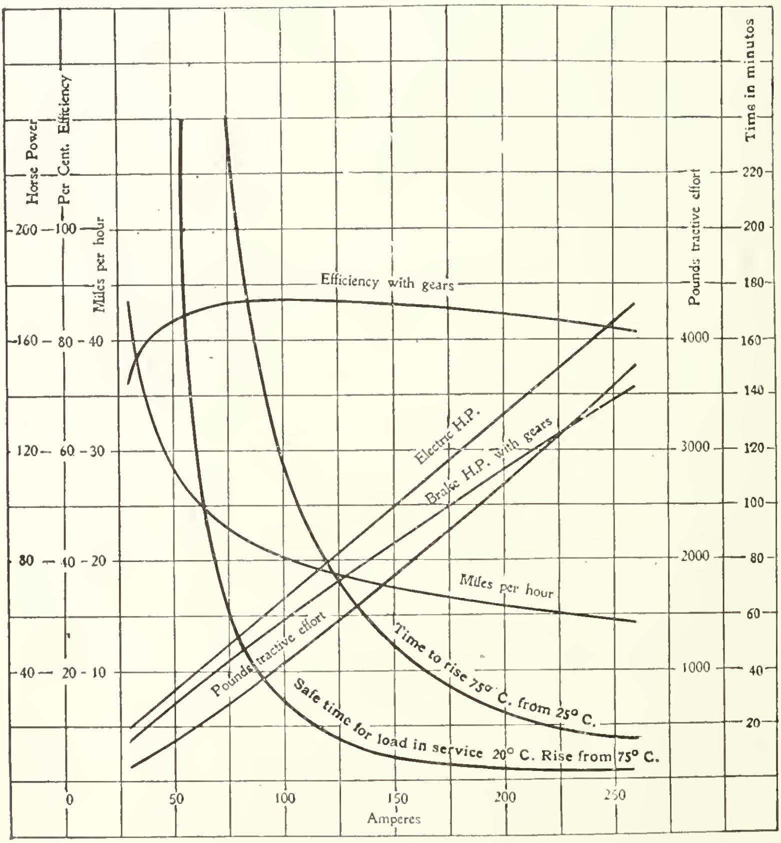


FIG. I—CHARACTERISTIC CURVES OF A RAILWAY MOTOR

Frequency and duration of stops—1 per mile, 10 seconds each.
Average line voltage—500.
Rate of acceleration—1.5 miles per hour per second.
Rate of braking—1.5 miles per hour per second.
Train resistance—by Blood's formula.

The characteristic curves of the motor to be applied to this case are shown in Fig. 1. The iron loss curves of the same motor, plotted in terms of watts and voltages on the motor, for a number of different

currents, are shown in Fig. 2. From these curves and the foregoing assumptions the curves shown in Fig. 3 are constructed. This figure shows the speed of the car, the current in the motor and the voltage on its terminals, at every instant during the cycle from starting to stopping. The next step is to calculate the average loss, or heating effect.

The electrical losses are divided into two classes, viz., those in the windings, or copper losses, and those in the core, or iron losses. The copper loss, being the product of the square of the current by the

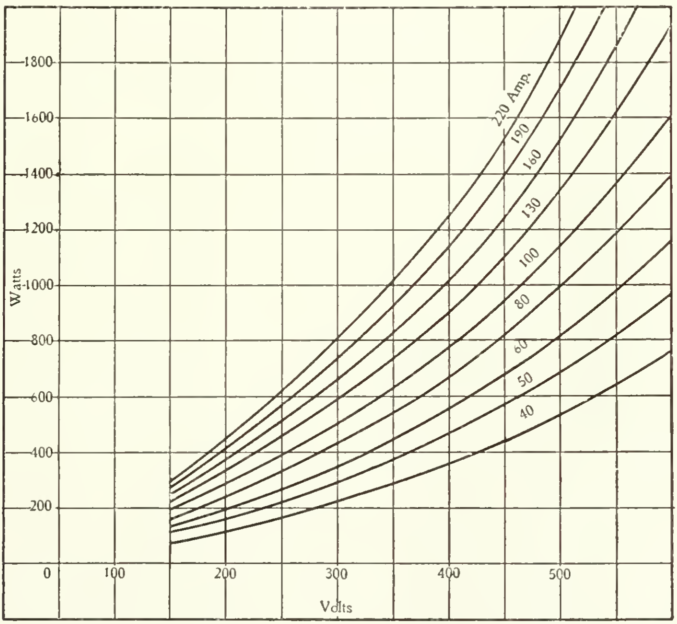


FIG. 2—IRON LOSS CURVES OF A RAILWAY MOTOR

resistance of the windings, is proportional at any instant to the square of the current. The average copper loss is, therefore, proportional to the average of the squares of the currents during successive intervals. The current which, when flowing continuously, will give the same average loss, will be the square root of the average of the squares—in other words, the *equivalent* heating current is the square root of the mean square current. This may be found in Fig. 3, by squaring a suitable number of values of the motor current and plotting these squared values on the time base. A curve may be drawn

through these points, integrated and averaged over the total time of the cycle (150 seconds in this case). The square root of the mean square value thus found shows that the equivalent current is 56 amperes. This current with a total resistance of the windings (at running temperature) of 0.184 ohm gives an average copper loss of 578 watts.

The iron loss is calculated from Fig. 2. At the start the current per motor is 134 amperes. At 200 volts this current gives an iron loss of 345 watts; at 350 volts, 750 watts, and at 500 volts, 1 360

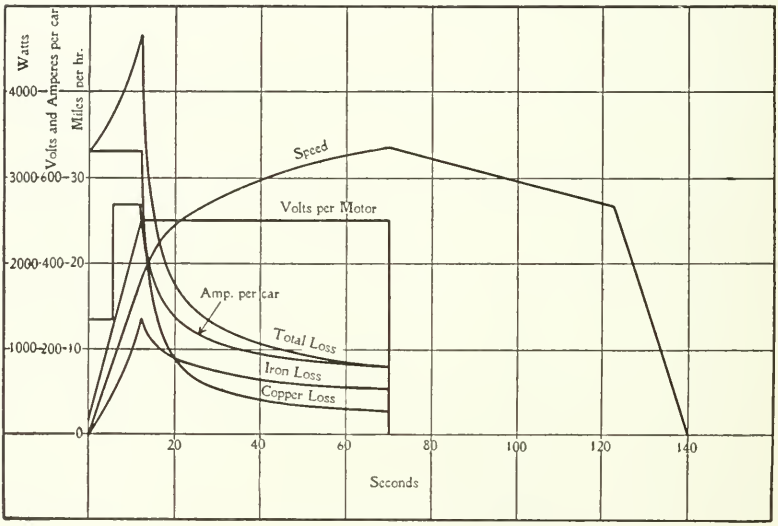


FIG. 3—CURVES OF SPEED, CURRENT, IRON LOSS AND COPPER LOSS

watts. At the end of 20 seconds the current has dropped to 68 amperes per motor. At 500 volts 68 amperes gives an iron loss of 890 watts. Other points may be found in the same way and the curve of iron loss plotted and integrated. In Fig. 3 the average iron loss is 303 watts. Therefore the total average copper and iron loss amounts to $578 + 303 = 881$ watts. It follows then that, in order to reproduce the heating conditions of this service in a shop test, all that is necessary is to run the motors at 56 amperes, which gives the average copper loss, and at such a voltage as gives, with 56 amperes, an iron loss of 303 watts. This equivalent voltage is found by reference to Fig. 2 to be 290 volts.

The foregoing analysis may seem to indicate that a large amount of calculation is necessary in order to select a motor for properly

meeting given conditions, but this is not the case. The various cycles of work the motor has to do should by all means be laid out and the equivalent heating current and the average voltage on the motor determined. But it is unnecessary to go into the refinements of iron loss to the extent that is done in this analysis. The average voltage on the motor is usually below 250 volts, and for all such work an equivalent voltage of 300 may be taken for the continuous test. For interurban service, where a high average voltage on the motor is maintained by reason of the smaller number of stops, an equivalent voltage of 400 will suffice.

Therefore, if the continuous capacity of railway motors is stated in terms of current at both 300 volts and 400 volts, this information will cover all classes of service with necessary precision.

From the fact that the allowable heating current of the motor in the foregoing example is 60 amperes at 300 volts, and 55 amperes at 400 volts, it will be seen that the exact equivalent voltage is not necessary for the test. The temperature of the armature does not rise in proportion to the total loss in it, as the highest voltage gives higher speed and, consequently, better ventilation.

The above analysis shows how to find the average heating effect of a single cycle. If the service over the entire line is about the same the determination of a single cycle will suffice. If, however, there is a difference due to grades, loads, stops or schedule speed, different cycles should be calculated, and the heating effects averaged. This method may be used where the losses are so distributed as not to allow the temperature to increase appreciably during any one cycle. Most roads, however, have heavy grades to surmount, or periods of the day during which the loading of the motors is much heavier than the average.

The time curve, given in Fig. 1, showing the time the motor will carry any load with a rise of 75 degrees C., starting cold, is the familiar "Load and Time" curve. A reference to this curve will show at the one hour point, the horse-power rating of the motor according to the old system. It also shows the allowable time the motor may carry any current above its rated continuous current or during which the square root of mean square current may reach any given value. It is plotted on the basis of an additional rise of 20 degrees C. in windings when the motor is already running at its average temperature, and thus gives a definite idea as to the temperature that may be expected in the worst

conditions. In case the motor is worked at a low average temperature, the time shown in this curve may, of course, be increased.

The writer has not advocated any particular method of *rating*, as he believes that the mere question of rating is of secondary importance when compared to a correct statement of capacity. If a rating is desired for comparative purposes it may be given in the continuous capacity in amperes, but all calculations should be based on complete information which should be furnished by the manufacturer as follows:

1—Curves of speed, tractive effort and horse-power of the motor within the limits of its commutating capacity and mechanical strength.

2—A statement of the currents the motor will carry continuously at 300 volts and at 400 volts.

3—A curve showing the allowable time any load above the continuous current may be carried when the motor is already heated in service.

4—A curve showing the time the motor will carry any load within its capacity with a rise of 75 degrees C., starting cold.

It is believed that the simplicity, completeness and accuracy of this method of stating the capacity will commend itself to any one who has anything to do with railway motors.

It reduces the question of the loads the motor can carry in service to a simple shop test that anyone can make with a good ammeter and voltmeter.

It furnishes the information necessary to determine the limiting lengths of grades and hours of overload.

It defines the capacity of a motor in such a way that its fitness for any class or condition of service may be determined.

The following objections to this method of stating capacity have been raised:

1—That "it ignores the interchange of armature and field heat."

2—That "it assumes the same conditions of ventilation on the testing stand as exist in operation."

3—That "the voltages which were selected for the standard shop test are improperly chosen."

In answer to the first objection it need only be said that a test in which the motor is run with the average losses properly distributed between the copper and iron cannot "ignore the interchange of field and armature heat." The conditions of internal ventilation are practically the same, whether the motor is on the testing stand or in service, and the interchange of heat will therefore be the same.

The second objection, that the method assumes the same conditions of ventilation in a shop test as exist in service, is without foundation. It is well understood that the conditions of external ventilation which exist under a moving car will give a very much less temperature rise than the same losses in the motor will produce in a shop test. For example, the actual temperature rise in average service would probably not exceed 60 degrees C., with the same losses which would give a rise of 75 degrees C. in a shop test.

It will be seen by this that the method does not assume the same conditions of ventilation in shop test as in service. It does assume, however, that the entire motor will run cooler in operation than in a corresponding shop test, and this assumption is supported by reliable tests. It is evident that with an enclosed motor the total heat must be dissipated through the outside shell, and it follows at once that as long as the amount and distribution of the losses are the same in each case the relation between the armature and field temperatures will remain practically the same, whether the motor be run in shop or in service.

Tests made under the supervision of the writer have repeatedly shown that this is the case, whether the temperatures are measured by thermometer or by resistance methods. As would naturally be expected, however, the results obtained by the latter method are much more consistent and reliable.

Service tests made under conditions of average city service gave a temperature rise between 25 and 30 percent below that produced by the same average losses in shop test. This ratio, however, will not be the same for all classes of service. Its value depends on a number of conditions, such as the schedule speed, which determines the average velocity of the air about the motors; the amount of obstruction to the air circulation about the motors; the length of stops, during which the heat will be dissipated at practically no greater rate than in a shop test; the state of the weather, including the temperature, velocity of the wind, etc., and, to some extent, the gear ratios used. Further data are needed to cover all classes of service, but it is safe to assume that the temperature rise in all motors in ordinary street railway service will be 20 percent less in a shop test giving the same average losses properly distributed. For high speed work a reduction of 25 percent may be counted on when the motors are so situated on the trucks as to have good air circulation. This is very important as there have been cases where the motors were so boxed in as to run about as hot in service as on the testing stand.

The third objection, in regard to the voltages selected for the standard shop tests, is also untenable. In the light of facts it is difficult to see any basis for this objection. The voltage of 300 was selected for the standard shop test because that voltage, with the continuous equivalent of the service currents, will give an iron loss equal to or somewhat greater than the average iron loss in the ordinary city work. As stated in the quotation above, the average voltage on the motor is usually below 250 volts. This, of course, means the average over the entire time the motor is in operation, including coasting and stops. In the example cited, which approximates suburban service, it was clearly shown that the average iron loss would be reproduced by running the motor in the shop test at 290 volts. The iron loss in a railway motor is a very complex function of current and voltage, increasing with both; but tests and calculations show that the voltage, of 300 for the continuous shop test will fully cover the average conditions. It is not claimed that this will give the exact average iron loss in every class of city service, but the results will be close and it will be found that where the service iron losses average less than that given by 300 volts the schedule speed is also low, so that the ventilation is not as good as in the average case, and the temperatures of the motor in service and shop test will therefore still bear the same relation. Thus, although the voltages of 300 and 400 may have been chosen arbitrarily, there were good reasons for the choice.

The purpose of such tests is to secure a standard test for railway motors that will not only serve as a basis for comparison between different motors, but will also be a measure of their capacity for service conditions. For comparing motors of different construction a standard test is absolutely necessary, and it can be made only in the shop, where all conditions are entirely under the control of the engineer. A test which consists merely in keeping a constant load on a motor running in a place where it is protected from drafts is certainly capable of much greater accuracy than any attempt to make in service an all-day test under uniform conditions. It is true that in order to get full advantage of the results of the shop test it is necessary to apply a constant which is determined by service tests. But these service tests need not be made with each and every motor under all the different conditions. The constants should be practically independent of the motor, and once obtained on one motor should be approximately correct for all.

THE OSCILLOGRAPH ON THE TEST FLOOR

H. H. GALLEHER

THE oscillograph is in form a very sensitive, perfectly dead beat, moving coil galvanometer which, when undamped, may have as small a periodic time of oscillation as one ten-thousandth of a second. Its self-inductance and capacity are practically nil. Its deflection at any instant is accurately proportional to the instantaneous value of the current flowing through it even with a frequency as high as 300 or more periods per second. Thus it constitutes an accurate instantaneous ammeter or voltmeter. These in-

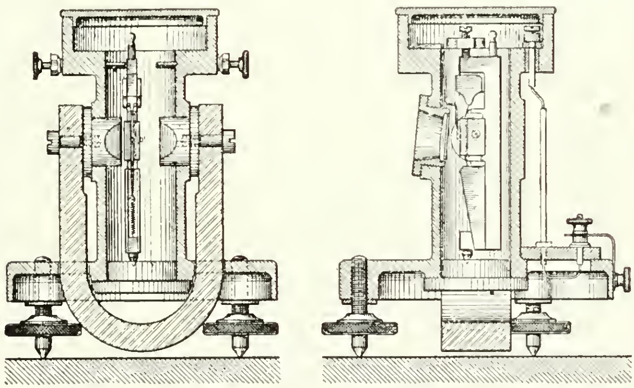


FIG. I—CROSS-SECTION OF OSCILLOGRAPH

View of a commercial form of moving coil instrument. One element is removed for the sake of clearness.

stantaneous values can be visibly observed on a revolving mirror, thrown on a tracing table and sketched with a pencil, or recorded on a photographic plate. These observations can be continued for any length of time and the instrument becomes, on the test floor, an indicating and recording voltmeter, ammeter, wattmeter, frequency meter, power-factor meter, etc.,—all combined in one—and fulfills all requirements in a very satisfactory way.

For example, it will readily give either the maximum, minimum, average or the square root of the mean square value of any wave form; the ripple of a direct-current wave resulting from commutation, or the harmonics due to disturbances on the lines. However, the oscillograph does not find its greatest use as a substitute for the watt-

meter, ammeter, etc., in regular routine work because all these latter instruments are available in such form that they are better adapted than the oscillograph to their specific uses. However, each of these instruments is adapted to but one class of work and when in special work an instrument of proper design and capacity is not available, the oscillograph readily adapts itself to the deficiency—not, however, until it is calibrated for such work, which calibration in most cases is a relatively simple matter. Then too, the oscillograph will adapt itself to some work for which none of the regular standard instruments are available.

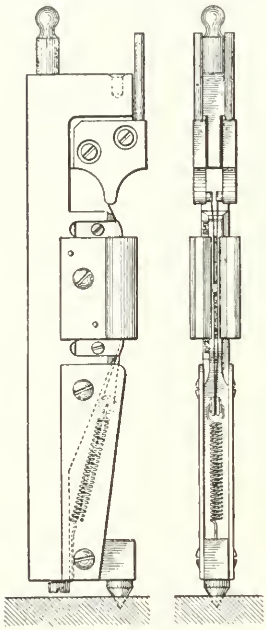


FIG. 2—DETAIL VIEW OF ONE ELEMENT OF OSCILLOGRAPH

Most oscillographs now have two or more elements so that two or three wave forms can be observed simultaneously; e. g., the current and voltage of each phase of a three-phase line or the current in the field, armature and line of a motor or generator, etc. Fig. 1 shows a cross-sectional view of one form of moving-coil oscillograph. This particular instrument is a two-element oscillograph. Fig. 2 is a sketch of one of the elements, which consists of a pair of very thin metal strips properly supported and kept under considerable tension in a strong magnetic field. Across these strips a very small, light mirror is fixed. A beam of light is thrown on this mirror and when current flows through the strip, the deflection of the mirror causes the spot of light reflected from it to move. With a direct current the mirror takes up a stationary position, which is a measure of the current value. With an alternating current the strip and mirror vibrate from side to side in exact unison with the current value so that the position of the mirror and its spot of light at any instant is a measure of the instantaneous value of the current passing through the strip. The zero value is recorded by means of the reflection from a fixed mirror. If, now, a suitably arranged set of mirrors be revolved at right angles to the direction of motion of these reflected spots of light, a curve of the instantaneous values of current may be seen.

In taking a magnetization curve a question may arise as to the wave form. This may be observed by means of the oscillograph. If the machine supplying power is over-loaded, unbalanced, of faulty design, or if there is a large amount of ohmic resistance in the line, it is immediately made apparent that the wave is far from a sine wave form. A tracing or photograph of the wave may be taken and the test continued, after which the results may be corrected by reducing them to the equivalent sine wave, or better still, the resistance may be reduced, some of the load may be taken off the machine or some other change may be made to bring the wave back to the sine form.

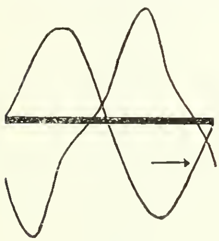


FIG. 3

For example, Fig. 3 gives the voltage wave form of a generator on normal load, which is a sine wave, and also, superimposed on it, a wave form of the same machine when carrying a heavy magnetizing current. In this case a careful tester, with good instruments and a well-designed generator, might easily get an iron loss from five to ten percent too low without suspecting the fact. Occasionally faulty design can be traced directly to incorrect design data obtained on circuits with bad wave forms. Anyone who is unaccustomed to observing the wave form of machines under the different loads imposed during a test, would be surprised at the tales told by the oscillograph.

Assuming that a circuit supplied from a mercury rectifier is being investigated; if there were not a complete assortment of instruments at hand, it would be difficult to find out what relation exists between the alternating and direct-current components of the apparatus. The oscillograph, however, serves the purpose of a permanent-magnet, induction-type and moving-coil instrument combined. In short, it will give all the characteristics of the circuit and will often explain many puzzling discrepancies. This is well shown in Fig. 4, which is a rectified direct-current wave from a mercury rectifier. In this case, the three different types of ammeters in common use would give three different current readings, none of which would give the results generally desired. By recording a

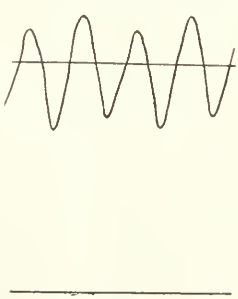


FIG. 4

known direct current from a storage battery on the same film, all the characteristics and values of the rectified direct-current can be very quickly determined by comparison.

Again, in the investigation of power-factor, the whole story is put down in black and white and there can be no question involving the accuracy of a wattmeter on low power-factor. For the study of phase relations and unbalanced effects, it is the only instrument that will give any tangible information, and it is sufficiently accurate for all requirements for this kind of work. Fig. 5 shows the phase relation and the potential difference curves of a two-phase rotary converter and irregularities due to sparking. Fig. 6 shows a power-factor of 97 percent lagging current.

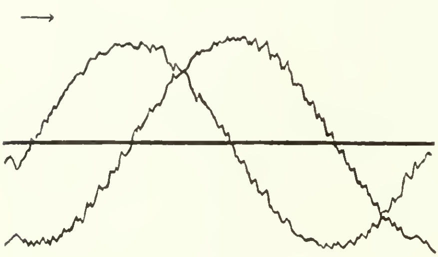


FIG. 5

The oscillograph means to most persons a very delicate instrument which is liable to get out of order and which requires an expert instrument maker to repair. To many it is an instrument which can be used only by an experienced man. It is not long since such was the case, but, fortunately, to-day there are several forms of oscillographs on the market which are portable and which can be set up and operated by a person with ordinary electrical engineering ability and which, when damaged, can be quickly repaired by any ordinary instrument man or mechanic. The oscillograph here described occupies a comparatively small floor space, an instrument insulated for potentials as high as 30 kilo-volts requiring a floor space of not more than two by four feet, including room for the motor, arc-lamp, revolving mirrors, resistance, etc. As regards the time required to prepare it for use, it can be connected up and put in operation as quickly as any other instrument, and does not require all the time of one man; in fact, three men can easily handle an ammeter, a voltmeter, a wattmeter and an oscillograph on ordinary tests.

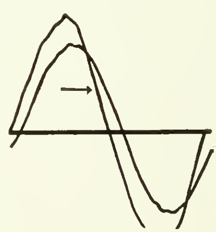


FIG. 6

The above-mentioned points are simply a few such as will suggest themselves to any test floor man or power-house man who is on the alert and who has the welfare of his plant at heart. They do

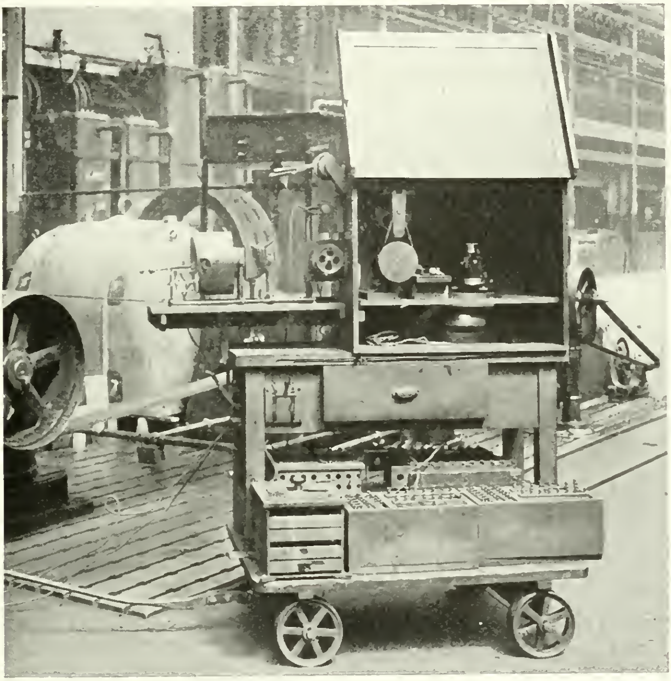


FIG. 7—OSCILLOGRAPH ARRANGED WITH PHOTOGRAPHIC OUTFIT

The oscillograph is mounted on the shelf within the box. When equipped for making oscillograms by the tracing method the outfit is much simpler and requires less space.

not show, however, the importance of this useful instrument for other work such as the locating of trouble and for development work and many other uses for which the oscillograph is admirably adapted.

METER AND RELAY CONNECTIONS (Cont.)

STANDARD RELAY CONNECTIONS*

HAROLD W. BROWN

IT is not practicable to include in the construction of circuit breakers such features as time element action and protection against over-voltage, under-voltage and reverse current, for in general these extra features can be best introduced by means of relays. Each kind of relay protects against one or more undesirable or dangerous conditions in the circuit which it controls. When these conditions occur it immediately begins to act. If it has a time element it allows the wrong conditions to continue to the end of the time limit, after which it makes a contact, thus closing the circuit that trips the circuit breaker; if the relay has no time element, it trips the circuit breaker as soon as the wrong conditions exist. Alternating-current relays are not ordinarily connected directly to the line which they control, but are nearly always connected to the secondaries of shunt and series transformers whose primaries are connected to the line. The various methods of connecting some of the more common types of relays are shown in the following diagrams. While the principles are the same for all kinds of relays the particular connections illustrated apply especially to apparatus of Westinghouse manufacture. In order to simplify the work of tracing connections, a method has been uniformly adhered to, of showing the *rear view* of both the external and internal connections of the instruments.

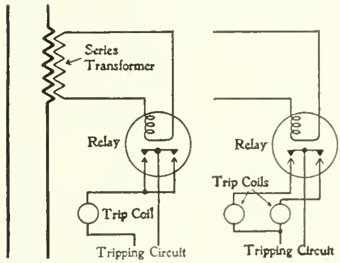
OVER-LOAD INSTANTANEOUS RELAYS

Relays of this type are made for use on single-phase or polyphase circuits. Fig. 1 (a) shows the connections of a single-phase

*Various types of relays are described in the articles on "Protective Relays," by Mr. Rypinski, appearing in the issues of the JOURNAL from January to June, 1908, inclusive. In the present article, therefore, only such references are made to the construction and operation of the instruments under consideration as are necessary to an understanding of the principles involved in making their connections. Furthermore, in order to avoid unnecessary repetition where no further principles would be developed, reference to the following types of relays has been entirely omitted, but should be noted in connection with this subject: Direct-Current Polarized Instantaneous Reverse Current; Direct-Current Over-Voltage; Auxiliary Direct-Current Definite Time Limit, and Bell Relay.

Some of the connection diagrams given correspond to similar diagrams in the article on "Protective Relays," but have been modified to show additional details.

relay for operating one trip coil and Fig. 1 (b) shows the change in connections for two trip coils. Fig. 2 shows a polyphase relay connected to a two-phase circuit. It can be similarly connected to two series transformers on a three-phase circuit. With this arrangement, however, the third phase is not fully protected. As long as the third line carries only the current flowing in the other two, it is protected by the two relay coils; but in case of a ground or any other condition by which it is possible for the current to flow by some other path, an excessive current may flow in the third line without sending a current in either of the relay coils sufficient to operate the relay. For full protection of a three-phase circuit, three transformers connected in "Z" should be used.



(a) (b)

FIG. 1—CONNECTIONS FOR SINGLE-PHASE OVERLOAD INSTANTANEOUS RELAY

(a)—Operating one trip coil.
(b)—Operating two trip coils.

Z-Connection of Series Transformers—Three leads are brought from the series transformers to the relay, as shown in Fig. 3. Assuming that the upper ends of the secondaries of the transformers in the three lines *A, B* and *C* are positive, one lead is connected to the positive end of transformers *A* and *B*, one to the negative end of *A* and *C* and the third to the remaining transformer terminals (the negative end of *B* and the positive of *C*). The first two leads connect to the outer terminal and the third to the middle terminal of the relay. The Z-connection may be made in twelve different ways, all identical in principle and equally effective. The only requisites are: that the positive ends of any two transformers shall connect to one coil; the negative ends of one of these and the third transformer shall connect to the other coil, and the common return for the two coils shall connect to the two remaining transformer

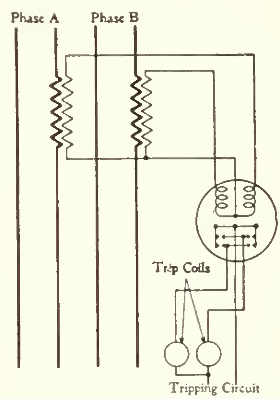


FIG. 2 — CONNECTIONS FOR POLYPHASE OVERLOAD INSTANTANEOUS RELAY OPERATING TWO TRIP COILS ON TWO-PHASE CIRCUIT

For one trip coil make connections of tripping circuit same as in Fig. 1 (a).

terminals. The vector diagrams in Fig. 4 show why a relay connected in this manner and having only two magnet coils will protect three lines.* The currents in the three lines are 120 degrees out of phase, as shown in Fig. 4 (a). The current in the right hand coil of the relay is the resultant of *A* and *B*. If *A* and *B* are equal the resultant is represented by *R* in Fig. 4 (b), which is equal to *A*. If *B* equals 0.5 *A*, the resultant is *R* in Fig. 4 (c), which is equal to 0.866 *A*. If *B* equals zero, the resultant is the same as *A*. For any other positive value of *B* between zero and *A* the resultant is between *A* and 0.866 *A*, so that the current in *A* required to operate the relay is practically independent of the current in *B*, so long as both have their normal direction and phase relation. Similarly, the current in *B* required to operate the relay is practically independent of *A* so long as both are in their normal direction. In other words, the right hand coil closes the tripping contact when there is an overload in either *A* or *B*, and does the same when there is an overload in both *A* and *B*. In the same way the left hand coil closes the contact when there is an overload in either *A* or *C*, or in both *A* and *C*, so that both *B* and *C* are protected by a separate coil, and *A* is protected by both coils of the relay.

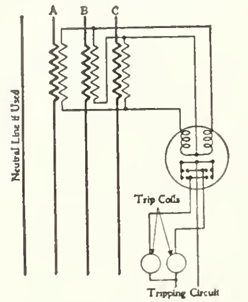


FIG. 3—CONNECTIONS FOR SAME RELAY AS IN FIG. 2, OPERATING TWO TRIP COILS ON THREE-PHASE CIRCUIT WITH Z-CONNECTED TRANSFORMERS

Two trip coils are required with Z-connected transformers to obtain full protection.

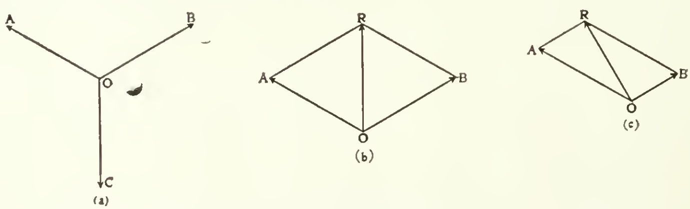


FIG. 4—VECTOR DIAGRAM OF CURRENTS WITH Z-CONNECTED TRANSFORMERS

(a)—Phase relation of currents in the primaries of the series transformers. (b)—Phase relation of secondary currents with currents in *A* and *B* (Fig. 3) of equal magnitude, giving a resultant *O R* equal to that in A. (c)—With current in *B* = one-half that in A, the resultant *O R* = 0.886*A*.

*For explanation of transformer connections see the first part of this article in the JOURNAL for May, 1908. For a discussion of "Vector Diagrams Applied to Polyphase Connections" see the JOURNAL for June, 1908.

ALTERNATING-CURRENT OVERLOAD TIME LIMIT RELAYS

These relays are so made that they do not operate instantaneously, but only when the overload has continued for some time. Three kinds are made:

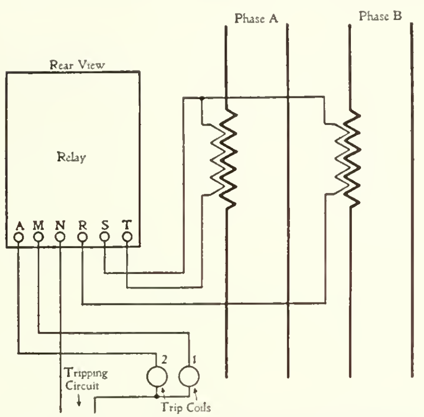


FIG. 5—CONNECTIONS FOR POLYPHASE OVERLOAD DEFINITE TIME LIMIT RELAY CONNECTED TO TWO-PHASE CIRCUIT

Polyphase Definite Time Limit Overload Relay—A relay of this type is shown connected to a two-phase circuit in Fig. 5. One coil of the relay is connected to R and S, and the other to T and S. The terminals A, M and N connect to the contacts in the relay. Fig. 6 shows the Z-connection for a three-phase circuit. For use with a single trip coil connect terminals A and M together.

Polyphase Inverse Time Limit relays have a time element in their operation, which depends on the amount of overload, the greater the overload the more quickly they operate. The connections for a three-phase circuit are represented in Fig. 7. The order of connections is different from that of the definite time limit relay, as will be seen by comparing Figs. 6 and 7. One coil of the inverse time limit relay connects to the second and fourth, and one to the fourth and sixth terminals from the left, as viewed from the rear. The relay contacts connect to the remaining terminals. If only one trip coil is to be operated, the first and third terminals are

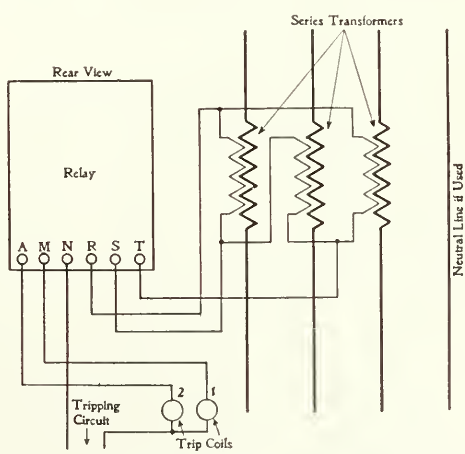


FIG. 6—CONNECTIONS FOR RELAY IN FIG. 5 ON THREE-PHASE CIRCUIT WITH Z-CONNECTED TRANSFORMERS

connected together. The diagram gives the Z-connection, for use on a three-phase circuit. Other connections are readily made as with the relays referred to above.

Single-Phase Inverse Time Limit relays are similar to the polyphase inverse time limit relays. They have only one magnet coil, and therefore two relays are required on polyphase circuits. They are made for either "shunt" or "series" tripping. In shunt tripping, the relay closes a separate circuit connected across a constant potential line thus operating the trip coil. All the relays heretofore described were made for shunt tripping. Figs. 8, 9 and 10 show the connections of the single-phase relay made for shunt tripping, as

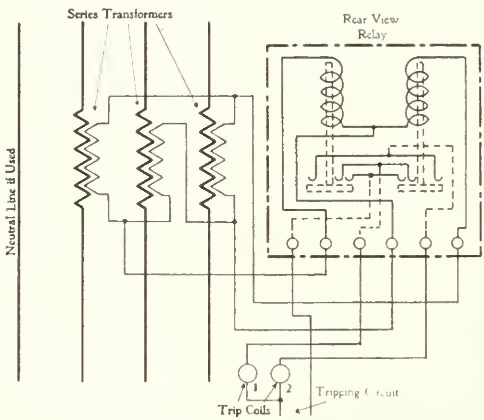


FIG. 7—CONNECTIONS FOR POLYPHASE OVERLOAD INVERSE TIME LIMIT RELAY ON THREE-PHASE CIRCUIT WITH Z-CONNECTED TRANSFORMERS AND SHUNT TRIPPING CIRCUIT

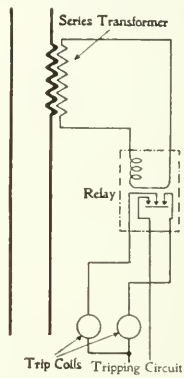


FIG. 8—CONNECTIONS FOR SINGLE-PHASE OVERLOAD INVERSE TIME LIMIT RELAY FOR SHUNT TRIPPING

applied to one, two and three-phase circuits.* In Fig. 8 the connections are simple, for there is only a single transformer, a single relay coil and two trip coils operated by the relay. Fig. 9 is similar to Fig. 8, but it represents a two-phase circuit with two relays to protect it. A common line is used from the two transformers to the two relays, to save the necessity of an extra line between transformers and relays. The contacts in the two relays are in parallel, so that if either relay operates it opens the circuit breaker. The connections to the relays are the same in Fig. 10 as in Fig. 9, except that in Fig. 10 there are three transformers on a three-phase

*Two trip coils are shown in each case. Only one is required if only one circuit breaker is to be opened. In that case the two outer terminals at the bottom of the relay are connected together.

circuit, and they are Z-connected, so that each relay protects two lines.

Series tripping is different from shunt tripping in that the series transformer furnishes current for the trip coil as well as for the relay, thus making a separate tripping circuit at constant potential unnecessary. Series trip coils have fewer turns and larger current capacity than have the shunt trip coils, for the series coils carry the current of the series transformer during tripping. A series trip relay is shown in Fig. 11, connected to a single-phase line. When current is flowing normally it passes from the top of the series transformer to the right hand side of the relay, through the relay coil, through the relay contact, out at the bottom, and back to the series transformer without passing through the trip coil. In parallel with the relay contact is another circuit, which connects to the point inside the relay between the coil and the contact, and leads out to the upper left-hand terminal, where it connects through the trip coil to the series transformer. The resistance of this circuit is high enough so that practically no current passes through the trip coil when the relay contact is closed, but as soon as the contact is opened, the current is forced to go through the trip coil, thus tripping the circuit breaker.

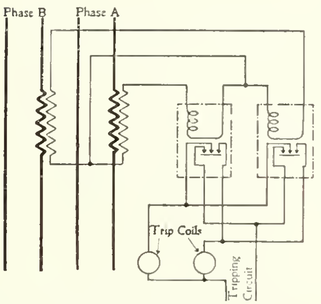


FIG. 9—CONNECTIONS FOR SAME RELAY AS IN FIG. 8 ON TWO-PHASE CIRCUIT

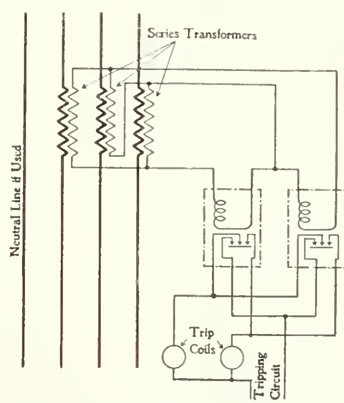


FIG. 10—CONNECTIONS FOR SAME RELAY AS IN FIG. 8 ON THREE-PHASE CIRCUIT WITH Z-CONNECTED TRANSFORMERS

The connections in Fig. 12 are the same as in Fig. 11 except that there are two series transformers and two relays, protecting a two-phase circuit. Instead of one trip coil, two may be used, the first being connected to the upper left hand terminal of one relay, and the second to the corresponding terminal of the other. The other ends of the trip coils are joined together, and connected to the

series transformers and to the lower terminals of the relays. Both coils are here required for full protection, for each protects only one phase. Another method of connecting is to have both trip coils in

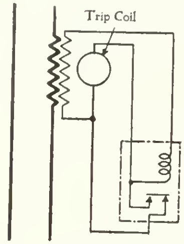


FIG. 11—CONNECTIONS FOR SINGLE-PHASE OVERLOAD INVERSE TIME LIMIT RELAY FOR SERIES TRIPPING

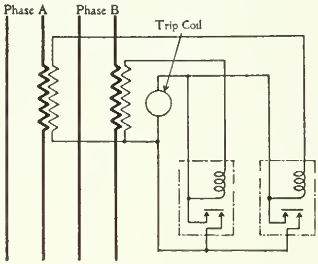


FIG. 12—CONNECTIONS FOR SAME RELAY AS IN FIG. 11 ON TWO-PHASE CIRCUIT

series. In this case the two may be on different circuit breakers, for each trip coil will operate in case of an overload in either phase.

To fully protect a three-phase circuit with series tripping relays the transformers must be Z-connected and there must be two trip coils, as shown in Fig. 13, whereas, only one trip coil is required with shunt tripping. One relay and trip coil protects two lines, and the other relay and trip protects the other two lines. The two trip coils must be connected to the same circuit breaker in order that it may be opened whenever there is an overload on any line. Various other methods could be employed for connecting to three-phase circuits for series tripping, but they do not protect the circuit in every respect.

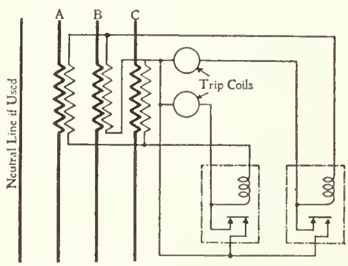


FIG. 13—CONNECTIONS FOR SAME RELAY AS IN FIG. 11 ON THREE-PHASE CIRCUIT WITH Z-CONNECTED TRANSFORMERS

(To be continued.)

THE JOURNAL QUESTION BOX

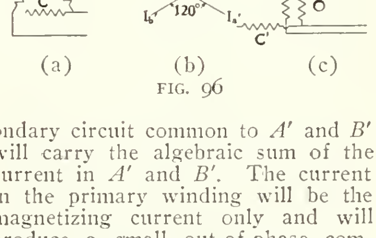
Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

96—VOLTAGES ON STAR-DELTA CONNECTION. In case the secondary winding in one transformer of a star primary, delta secondary installation should become open circuited, what would be the voltage between any two wires of the circuit? G. A. R.

If the common point of the star-connected primaries is connected directly to the neutral of the generator either through a fourth wire or through the ground, the voltage relation will be undisturbed and the two remaining transformers of the delta connected secondary combination will continue to operate at full voltage with the proper phase relations as *V*-connected transformers. The total capacity, however, will be but 86.6 percent of the sum of the capacities of the two transformers. The current relations for primary and secondary are shown in Fig. 96(b) where *Ia* and *Ib* are the currents in *A* and *B* respectively and *In* is the current in the neutral wire or ground. *In* is $\sqrt{3}$ times as great as *Ia* or *Ib* and there is no current except magnetizing current in *C*.

If the common point is not connected to the neutral of the generator the opening of one transformer on the delta side practically converts the corresponding primary on the star-connected side into a choke coil across which the voltage is increased, thus shifting the potential of the common point until the two remaining transformers are in 180 degree relation. That is, they will act as two single-phase transformers connected in series across one phase of the primary circuit. The voltages and currents in the two delta-connected secondaries, *A′* and *B′* will now both be in the same phase. These voltages, however, will be reduced to 86.6 percent of their original values and while the voltage actually generated in the open-circuited secondary *C′*, Fig. 96(a) will be 1.5 times its original value, the potential across the two terminals will be zero, as shown in Fig. 96(c). The entire voltage generated will in this case operate across the point of the open circuit which is assumed to be inside the terminals of the transformer. The voltage relations under these conditions are shown in Fig. 96(c). The wire of the sec-



(a) (b) (c)

FIG. 96

ondary circuit common to *A′* and *B′* will carry the algebraic sum of the current in *A′* and *B′*. The current in the primary winding will be the magnetizing current only and will produce a small out-of-phase component in the other pimaries.

The above discussion does not apply to the three-phase core type transformers on account of the interrelation of the three fluxes which prevents the shifting of the neutral point. J. W. W.

97—HOW DOES A Z-CONNECTION DIFFER FROM A DELTA CONNECTION with reference to connecting up instantaneous over-

load relays, and is there any reason why a V-connected set of series transformers would not answer the same purpose?
C. G. R.

The relay should not act when the current in each of the phases is materially lower than the tripping value, even though the vector sum of the currents in two phases may be greater. The Z-connection secures the desired condition, as the effect of an overload on one phase only is nearly the same as an overload on all phases. Thus, action of the relay is determined by the maximum current in any one phase rather than the sum of the currents in the different phases. The difficulty with using V-connected transformers is that one phase is left unprotected whereas the Z-connected arrangement, protects all three phases. These points were fully explained in the article on "Protective Relays" by Mr. M. C. Rypinski in the JOURNAL for March, 1908, p. 173. See article by Mr. Harold W. Brown in this issue.

98—WHY IS AN AUTO-TRANSFORMER USED FOR STARTING INDUCTION MOTORS instead of a transformer with the proper taps?
H. D.

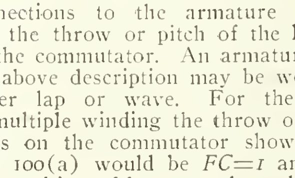
The auto-transformer is used because of the saving in material, both copper and iron. See question and answer No. 6 appearing in the JOURNAL for January, 1908.

99—Why are AMMETER SHUNTS NOT USED ON LOW VOLTAGE ALTERNATING-CURRENT CIRCUITS as on direct current?
C. A. B.

The ammeter shunt for use on alternating-current circuits of sufficient size to give the necessary drop for use on an ammeter would be very cumbersome. On account of the skin effect which has to be taken into consideration in alternating-current work (skin effect is the property possessed by alternating currents of seeking to flow on the surface of conductors instead of with equal density throughout their entire cross-section) the ammeter shunt would have to be of special and probably expensive design made up of a large number of small conductors in order to avoid great changes in calibration for different frequencies. The cast-iron type of ammeter shunt such as is often used with direct-current ammeters and constructed with numerous flanges to increase the radiating surface would be especially affected by changes in frequency and would therefore be practically useless with alternating-current ammeters. Furthermore, the most important consideration, the combination of a resistance (the shunt) and an inductance (the meter coils) in parallel would cause serious variations in the proportions in which the currents in the two paths would divide when changes in frequency occurred.
H. W. B.

100—ARMATURE WINDING. What formulas would be used in winding and connecting a direct-current motor and what would be the throw of the armature leads at the commutator, the specifications being as follows: Voltage — 230; Poles—4; Brush holders—4; Brushes—4; Armature slots—29; Coils per slot—3; Throw of coils—1 to 8; Commutator segments—87?
R. D. G.

With the number of commutator bars, armature slots and throw of coils known it remains to find the relative position of the commutator



(a) FIG. 100 (b)

connections to the armature slots and the throw or pitch of the leads on the commutator. An armature of the above description may be wound either lap or wave. For the lap or multiple winding the throw of the leads on the commutator shown in Fig. 100(a) would be $FC=1$ and 2. The position of bars 1 and 2 relative to slots A and B should be such that the mica segment between bars 1 and 2 shall be opposite a point on the armature half way between A and B. For the wave or two-coil winding F Fig 100(b) is to be considered as bar 1. To find bar C add 3 to the

total number of active bars and divide by 2. Applied to the case stated above, $C=(87+3)\div2=45$; therefore the throw of the armature slots on the commutator equals 1 and 45 or a pitch of 44. The position of bars F and C relative to armature slots A and B is found as follows: There being three times as many bars as slots and the pitch AB being 7, the pitch of $ED=21$. Then, $FE+DC=FC-ED=44-21=23$.

When $FE+DC$ is even, $FE=DC$.

When $FE+DC$ is odd, $FE+1=DC$.

Therefore, in this case, pitch $FE=11$, and $DC=12$.

Bars F, E, D, C, will therefore be Nos. 1, 12, 33 and 44 respectively.

The above applies to any two-circuit winding whether there are idle coils or idle bars, so long as only active bars are considered. F. A. R.

101—ARMATURE WINDING. In the case of a 50 hp four-pole, direct-current crane motor with forty-five slots, three coils per slot, 135 commutator bars, why does the lap-wound type have a higher speed than the wave wound at the same voltage? What is the result as regards speed and current consumption in both types of armature when operating the motor with two sets of brushes instead of four?

T. S. W.

The connections to the commutator bars of a series or wave type of armature winding are such that there are two parallel windings from the positive to the negative brushes, and hence two brushes may be used with the four-pole type of machine, although commutation may be improved by the use of four brushes. In the multiple or lap-wound type there are four parallel circuits for the current and two brushes cannot be used unless the commutator bars are cross-connected. In the series winding the leads from each coil are connected to commutator bars approximately diametrically opposite while in the multiple winding the corresponding leads from the coils are connected to adjacent commutator bars. The multiple winding requires approximately double the speed to generate a given counter e.m.f. As the speed and current capacity of the multiple winding are twice those of the series winding, the capacity of the multiple-wound armature is proportionately greater. The speed of a series-wound armature is not changed by the use of two brushes instead of four.

102—HOW IS A HEAT TEST APPLIED to a direct-current and an alternating-current generator before going into service at the station? A. F. L.

The heat run is sometimes made, especially on alternating-current generators, for the purpose of drying out the insulation before the machine is put into regular service. The armature terminals are short-circuited and full-load armature current is obtained by a field current of the proper value. Ammeters are connected in the armature leads with short-circuiting switches so that the current flowing may be quickly determined. Such a test is continued for twelve hours or more, depending on the design of the machine, i. e., whether the construction is such that it has good ventilating properties. The insultation resistance test, measured by voltmeter, is ordinarily used to determine the condition of the insulation as the test is continued. When it is desired to run a full-load test on a machine and it is not possible to run it on a line load, water rheostats may be employed. These can be made in a rough form by using barrels, with scrap iron or sheet iron terminals and an electrolyte of salt and water or acidulated water. The purpose of the acid or salt is to increase the conductivity of the water. The barrels can be used in series or parallel arrangement to suit the load and voltage of the machine under test. One plate of each rheostat is hung so that it can be raised or lowered to give adjustment of the load. In one case a load was obtained for a high voltage generator by connecting the leads from the armature to plates lowered into a river near the power house, the running water making it possible to operate at a higher current density than if barrels had been

used. See the article by Mr. Wilson in the JOURNAL for November, 1907, p. 611; also an article by Mr. Olin in the JOURNAL for April, 1908, p. 235. W. A. D.

103—What is meant by the term "EQUIVALENT SPARK GAP"? Also, what is meant by "a low equivalent lightning arrester"? D. D. H.

The definition of the term "equivalent spark gap" is given in an article by Mr. R. P. Jackson in the JOURNAL for March, 1908, p. 156, as follows: "By equivalent spark gap is meant that definite form of gap which, when placed in multiple with the lightning arrester, just fails to take the discharge. The length of this gap is the measure of the freedom of discharge of a lightning arrester." (A diagram showing the method of measuring equivalent spark gap is also given.) The ideal lightning arrester has a very low resistance to static discharge, that is, a small equivalent spark gap and a sufficiently high resistance to normal line voltage to prevent operation of the arrester except under abnormal rises of potential, such as surges due to switching or resulting from lightning discharges. See also an article by Mr. N. J. Neall in Vol. II., p. 224 of the JOURNAL. A low equivalent lightning arrester is a multi-gap arrester with part of the spark gaps shunted by an inductive resistance, there being a non-inductively wound series resistance connected between the series of multi-gaps and the ground connection. The purpose of this arrangement is to approach as nearly as possible the ideal conditions as stated above. For further information and connection diagram of this type of arrester, see an article by Mr. N. J. Neall, in Vol. II., p. 482 of the JOURNAL.

104—IN CALCULATING THE SIZE OF SHAFTS necessary to keep the deflection at the armature of a generator within certain limits it is usual to take into account in addition to dead loads a calculated unbalanced magnetic pull, due to displacement of the armature, of 1/32nd of an inch. As there can be no unbalanced pull if the armature is placed concentrically with the field magnets I cannot understand why this pull is taken into account. Further, I should like to know what fixes the usual deflection limit of 0.03 of an inch, as it appears to me immaterial whether the deflection be as great even as 1/8th of an inch, so long as the safe working stress is not exceeded, since the armature could be placed in the central position by raising the center of the bearings (if self-aligning) above the field center by an amount equal to the deflection. H. E.

It is true that there will be no unbalanced pull if the shaft and armature are exactly centered. However, it is very difficult to do this. There is more or less vibration and also wear in the bearings. An armature might be correctly centered when built but for safety it is considered advisable to make the allowance you mention.

The deflection limit is an arbitrary figure used only as an indication of the stiffness of the shaft, which is an important thing to keep in mind. A very flexible shaft renders the rotating part liable to vibrations due to unbalanced masses or to great deflection due to unbalanced magnetic pulls. It is practially impossible to center the rotating parts exactly; thus there is always some lack of uniformity in the magnetic pull. A stiff shaft facilitates good mechanical and magnetic balance. In electrical work it is not customary to use shafts in which the stresses will come anywhere near the safe working strength of the metal. A. K.

105—OPERATION OF RAILWAY MOTORS WHEN CROSSING SECTION BREAKS—Why has a railway motor a tendency to flash over if the current is not turned off when crossing a trolley section breaker? H. I. E.

With the ordinary length of trolley section break, the speed of the car is usually not sufficient to prevent the magnetism of the motor from dying down during the period that the current is off. The fields of

railway motors are ordinarily constructed with solid poles. The first rush of the current when the circuit is again closed will, therefore, not build up the fields as quickly as the armature. This retardation is due to the eddy currents that are set up in the solid iron of the fields. The result is an enormous rush of current until the armature counter e.m.f. rises, this current rush being accompanied by great field distortion with a consequent shifting of the neutral point which, in itself, is sufficient to cause very many cases of flashing.

106—ELECTROLYSIS (?) OF A LEAD WATER PIPE—A piece of lead water pipe located under the rails of an electric railway developed a leak. Upon taking it up it was found that all the pipe under and extending for some little distance on either side of the rails was "rotten," that is, could not be bent without opening up many cavities or holes and examination under a magnifying glass showed the section at the breaks to be granular. There was, however, no "pitting" either inside or outside. Could electrolysis cause this change in the nature of the metal without external pitting? O. P. L.

If the pipe was not pitted the trouble was not caused by electrolysis. It is probable that this trouble was caused by vibration transmitted from the rails of the track through the earth or other intervening material to the pipe, causing it to crystalize. There are cases on record where the lead sheathing of cables has been crystalized as a result of the continued vibration to which it was subjected during long hauls on freight trains. To prevent a recurrence of this trouble it is recommended that the lead pipe be buried deep under the tracks and surrounded with at least one foot of sand.

R. A. L. S.

107—INDUCTION MOTOR USED AS GENERATOR—Under what conditions will an induction motor act as a generator and what would determine the frequency and the voltage generated? A. J. H.

An induction motor operating on a circuit containing synchronous units may act as a generator and return power to the line when driven at a speed which is above that of synchronism and less than double that of synchronism. The frequency and voltage of the circuit will be that of the synchronous machines. The synchronous units may be synchronous generators, synchronous motors or rotary converters. The speed of the synchronous units, and consequently the frequency of the circuit will be decided by the governors of the prime movers driving the various generators on the circuit. The voltage of the synchronous units, and consequently that of the circuit will be decided by the excitation of the synchronous machines and can be varied by varying this excitation.

W. L. W.

108—WILL TWO 100 KW TRANSFORMERS IN MULTIPLE divide their load equally if the impedance of each is the same regardless of the relative values of resistance and reactive components making up this impedance? For example, assuming that one transformer has five percent resistance and 2.3 percent reactance and the other has five percent reactance and 2.3 percent resistance. W. C. S.

Yes, the currents in the two transformers will be equal when the impedances are equal, but they will not have the same phase relation with reference to the voltage. The angle of lag will, in each case, be directly proportional to the reactance, and indirectly proportional to the resistance; expressed in an equation:

$$\Theta_1 = \tan^{-1} \frac{x_1}{r_1} \text{ and } \Theta_2 = \tan^{-1} \frac{x_2}{r_2}$$

where Θ represents the angle of lag, x equals the reactance, and r equals the resistance. It is thus evident that the resultant or line current will be the vector sum of the two currents and that this resultant will be less than the arithmetical sum. The transformers will therefore be loaded heavier than if in each case the impedances were made up of the same reactance and resistance components respectively. It will be seen that the angle of lag of the resultant or line

current will be a mean average of the lag angles of the two transformer currents, because the latter are equal. This subject will be treated in an article to appear in an early issue of the JOURNAL.

109—TESTING ARC LAMPS FOR MUNICIPAL AUTHORITIES — What system of testing can be used to satisfy municipal authorities that any arc lamp which they may specify is really giving 2 000 c-p as per contract, without removing the arc lamp to the test room? H. H.

Although 2 000 c-p is a nominal rating for arc lamps which has been used extensively throughout the entire country, it is generally conceded that no commercial arc lamp will give 2 000 c-p; but where the term is used it is generally understood to mean a lamp consuming an average of 450 watts. In 1894 a committee of experts reported to the National Electric Light Association as follows: "Recognizing the difficulty, if not impossibility, of measuring with any degree of accuracy the illuminating power of the arc lamp, and the great necessity for a more precise definition and statement of the obligations of the producer of electricity for illuminating purposes to the consumer thereof, *be it resolved:* That in the opinion of this convention, what is ordinarily known as a 2 000 c-p arc lamp is one requiring an average of 450 watts for its maintenance, the measurements being made at the lamp terminals, where no sensible resistance is included in series with the arc. In case such resistance is used, it must be excluded in the measurement of the voltage." This method of rating arc lamps on the basis of energy consumed was fairly satisfactory until the introduction of the enclosed arc lamps. The characteristics of the open carbon arc, the enclosed carbon arc and other lamps of more recent design vary considerably. Some of the lamps recently placed on the market, for example, the metallic flame arc, give a better street illumination with approximately one-half the energy consumption. It is evident, therefore, that it is not fair to compare the illuminating value of arc lamps on the basis of energy consumed. Inasmuch as the lighting of streets is a matter of illumination produced rather than energy consumed, efforts have been made to establish a definite rating of arc lamps in terms of illumination produced rather than of energy consumed; *i. e.*, the average illuminating power of each unit should be comparable with, and have a value equal to, a known standard, at a proper relative distance. It is present practice to figure the illuminating value of an arc lamp from the photometric distribution curve of light in the vertical plane. This distribution curve can be taken in any photometric laboratory, and the illuminating curve plotted from it. Similar results can be obtained by measurement of illumination in the street by means of a luminometer or a street photometer. It is difficult to secure accurate results with devices of this kind. Such work should be done by some one who is skilled in photometer work and has a knowledge of the fundamental principles involved, and their application. C. E. S.

110—STORAGE BATTERY COUNTER-E. M. F. CELLS—What is the best way to cut down the line voltage for charging storage batteries without using counter-e.m.f. cells? The line voltage is 125 volts; the charging voltage 110 volts. I now have 48 cells of 24 ampere-hours capacity with five counter-e.m.f. cells in one side, but would like to do away with latter. A. E. J.

We know of no substitute for counter-e.m.f. cells for cutting down line voltage with the exception of a generator of the required voltage inserted in the line in place of the counter-e.m.f. cells. Fixed resistances will not accomplish the same result, since in placing the battery directly across the line, it is desired to start the charging of the cells with a current as high as 40 amperes. This would, therefore, necessitate a very low resistance, and since as the charge progresses, it is desired to have the counter-e.m.f. of the battery automatically cut down the charging current, a high resist-

ance would be required toward the latter end of the charge. This is automatically accomplished by the counter-e.m.f. cells. L. H. F.

111—USE OF INCANDESCENT LAMPS AS RESISTANCE TO SECURE FRACTIONAL VOLTAGES — What method should be employed in determining the proper resistance to be used in cutting down the voltage of a 110-volt electric light circuit by means of 16 c-p lamps where the reduced voltages are to be employed in various kinds of testing service and where no voltmeters or ammeters are available? For example, how many and what candle-power lamps should be used when six, ten, fifteen or thirty volts are desired? Is it feasible to use Ohm's law and standard lamp data for the calculations? C. H. S.

For general use where large reductions in voltage are required for various loads, this arrangement is not satisfactory. A much more convenient and effective arrangement would be obtained by the use of say fifteen storage battery cells arranged in series and provided with leads from the terminals of the various cells to a terminal board so that any desired voltages could be obtained. For the arrangement outlined, definite instructions cannot be given without data as to the currents that will be required at the voltages mentioned, as with lamps or other resistance used in series with the loads to reduce the voltage, a condition of constant current is more nearly approximated than one of constant voltage. For example, assuming the load to be of 11.1 ohms resistance and connected in series with a 104-volt, 16 c-p, 3.5 watt lamp across the 110-volt circuit; the load will take 0.54 amperes and have a drop of six volts. If now the resistance be increased from 11.1 to 19.3 ohms the drop in voltage across the load will be ten instead of six volts; the current, however, will fall only from 0.54 to 0.518 ampere. Assuming a load resistance of 30.5 ohms, the voltage drop will be fifteen volts with a current of 0.492 ampere. Again, with 72.3 ohms the voltage drop will be 30 volts and the current 0.415 amperes. This illustrates the wide variation of voltage drop across the load, resulting from even small changes of current value. The relation of load current to load voltage depends, therefore, on the resistance of the load or, if the load be a motor, upon the motor load. If a greater current be required than given in the above case, a number of lamps in parallel may be used. To determine the number of lamps in parallel required for this purpose, let K be the number of amperes required, then:

For	6 volts	use	$K \div 0.54$	lamps
"	10 "	"	$K \div 0.518$	"
"	15 "	"	$K \div 0.492$	"
"	30 "	"	$K \div 0.415$	"

If less current than would be obtained with the use of one lamp is desired, an eight c-p lamp, giving half the current, may be used; or two 16 c-p lamps in series will give practically the same current. It must be remembered, however, that when a number of lamps is run in series, the voltage per lamp may be so low that the filaments will be but slightly heated. The resistance is therefore greater than when the lamps are operated at their normal voltage. This change in resistance is negligible while the filament is hot enough to give light, but is considerable when it ceases to glow. Two 16 c-p lamps in series will therefore take a little less than half the current of one eight c-p lamp. The resistance of lamps varies with use, also the line voltage will affect the accuracy. The data given above for determining current and voltage drop may be represented graphically in the form of curves showing load current and resistance of load by using volts as ordinates and amperes and ohms as abscissae. H. M. S.

113—EDDY CURRENT LOSSES IN COPPER OF TRANSFORMER—Do not the eddy current losses in the copper of a transformer vary as the square of the frequency? In transformer testing this does not prove to be the case. Why? In these measurements the eddy current loss was obtained by subtracting the I^2R watts from the watts read with the secondary short-circuited (measured with precision wattmeter). G. D. B.

The magnetic field which produces eddy currents and the resulting voltage E vary directly as the frequency. The eddy current losses $=E^2 \div Z$ where $Z=$ the impedance of the local circuit and is made up of resistance r, independent of frequency, and reactance x, due to local flux around each conductor, set up by the current in the conductor and varying directly as the frequency. These components are at right angles; hence $Z=\sqrt{r^2+x^2}$. Hence, if the circuit were made up entirely of resistance, the eddy current losses, $E^2 \div r$, would vary as the square of the frequency—since E varies directly as the frequency. If it were made up entirely of reactance, the losses due to eddy currents, $E^2 \div x$, would vary directly as the frequency. Therefore, as E^2 is proportional to the square of, and x only directly proportional to the frequency, and as in any transformer, there is a combination of the two, the eddy current losses vary more rapidly than the frequency, but less rapidly than the square of the frequency. E. C. S.

112—In Re-Winding a Three-Phase Induction Motor for a given speed how may one determine the correct number of slots to span. Is it possible to double the number of poles per phase thereby reducing the speed one-half and still use the same throw? R. B. R.

A full pitch winding will have coils spanning a number of teeth which is equal to the total number of teeth divided by the number of poles. For example a full pitch winding in a 48-slot, four-pole machine would span $\frac{48}{4}=12$ teeth, that is, the coils would lie in slots 1 and 13. In practice, however, it is not customary to wind full pitch but to reduce the throw one or more slots to one-half the pitch throw. The throw is largely determined by the design. The above holds for diamond-shaped coils and not for the concentric type. Concentric coils are wound full pitch, *i. e.*, the average throw is as explained above. If the number of poles were doubled, using the same coils, a motor so arranged would run at one-half speed but the magnetizing current would be excessive unless the voltage were reduced at least 50 percent. The output would not be more than half and would be even less if the coils were originally wound nearly full pitch. Under any conditions this procedure would give a rather poor motor and is not advisable for a motor that is to be run continuously. G. H. G.

114—Is the Insulation of an open induction motor, exposed to fumes from a nitric acid still, liable to be greatly impaired. The motor runs a centrifugal pump which sprays acid into a tower to condense the fumes and the winding has been impregnated with acid. The motor is operated eight hours continuously every twelve hours at approximately three-fourths load, normal voltage and is in a rather damp place. What can be done to protect the insulation? A. G. W.

Ordinary insulation would probably not last for more than five or six months, depending on how dense the fumes are. A special impregnating compound is used on motors for such service. Either the coils are impregnated before the machine is wound, or else the complete machine is dipped in the material. This treatment adds materially to the life of the machine although it is not impervious to the action of the acid, especially if the fumes find small spots where the impregnating compound has not permeated the insulation, and which result in an eventual break-down. Various manufacturers have developed definite methods of treatment for apparatus applied to such service. Further information regarding such apparatus can be obtained from them. A. M. D.

Note.—In the answer to question No. 65 in the May issue the last sentence should read: "The effect, therefore, of changing the power-factor by variation of the field current of the synchronous machine is to cause one wattmeter to register a larger portion of the power than the other, the total amount of power, however, remaining the same."

THE
ELECTRIC JOURNAL

VOL. V. AUGUST, 1908 NO. 8.

Direct-Current Turbo-Generators

The article by Mr. J. S. S. Cooper on "European Practice in Direct-Current Turbo-Generators" in this issue of the JOURNAL gives an interesting description of some recent examples of European practice in the design and construction of direct-current turbo-generators. This type of generator has been designed and built to a limited extent for a good many years. The earlier attempts, however, left much to be desired and have proved only moderately successful. In addition to the inherent difficulties to be overcome in the building of the generators themselves, a further cause of the somewhat slow development is found in the more pressing demand for alternating-current turbo-generators and the wide field in that line. This has held back the development of the direct-current turbo-generator where the inherent limitations are such as to require speeds below those feasible for alternating-current work, and separate turbine development has also been necessary.

Recently in the United States the direct-current turbo-generator has been making a gradual and healthy progress; gradual in that time is being taken by manufacturers to thoroughly try out the different devices in practice before extensive manufacture; healthy in that increasing numbers of this class of machines are being put into commercial operation with results commensurate with those obtained with slow speed units.

It has been the belief of nearly all American designers that it was useless to attempt to develop direct-current turbo-generators using copper brushes, as they have proved a failure in slow speed machines; hence the almost universal use of carbon brushes in this country. It might be added that there seems to be a growing belief among European designers also that direct-current turbo-generators to be successful must have this kind of brushes.

One of the most noticeable departures from existing practice in ordinary direct-current work is found in the so-called radial commutator described by Mr. Cooper. This overcomes

some of the inherent defects of the ordinary type of construction when applied to long commutators for high speed work, and the results obtained so far have been very good.

On the whole, the present outlook for the direct-current turbo-generator is very promising, and it seems apparent that there will be a rapidly increasing field for it.

W. A. Dick

The Casino Technical Night School

There are numerous industrial schools in various parts of the country which offer specific instruction in the various trades, such as tool making, machinists', plumbing, pattern making, etc. There are also a number of manufacturing concerns which offer apprentice courses in various trades. The Casino Technical Night School, while serving the same general class of students, is fundamentally different in its aims and methods from either of the above in that no attempt is made to teach any specific trade. The aim is to give the student a systematic training in general subjects, comprising mathematics, physics, chemistry, mechanics, steam practice, electricity, mechanical drawing and shop practice. Sufficient laboratory work is provided to illustrate the fundamental physical laws and give a good foundation for the theoretical study in the class rooms. Instead of memorizing facts regarding a specific trade, the student studies the application of the elementary principles that underlie all classes of technical or trade work. He gets started right in his conception of fundamental physical facts, and above all trains his mind to think straight concerning that which his hands are doing in his daily work outside the school. He learns to reason rather than to memorize. He gets a good foundation upon which he can build sound judgment regarding the experiences of his daily life.

There is but one course of study, covering a period of three and one-half years, and all work is so classified and scheduled that the student knows at the very beginning what he must do before graduation. Attendance is open to anyone, although a large part of the students are employed by the Westinghouse companies. The enrollment has reached between three and four hundred and includes students of all ages and many nationalities, the greater part, however, being young apprentices.

The school is organized in a manner similar to a small col-

lege. There are regularly organized classes with all the enthusiasm and loyalty characteristic of any growing school. There are social, musical and athletic societies which are actively supported by the students.

The faculty is composed of thirty-five members, who are mostly technically trained men, engaged in active engineering work, in drafting and in other departments of a large manufacturing company. This fact tends to make the students interested both in their school and day work.

That graduation means something to the students and to their employers is shown by the fact that of those who have graduated in the past three years, all but five are still with their employers and practically all of these have received substantial promotion.

C. R. DOOLEY

Notes on A. I. E. E. Convention

The address of Mr. Henry G. Stott, retiring president of the American Institute of Electrical Engineers, at the Atlantic City convention was a plea for a broadening of the narrower definition of engineering and a larger activity of engineers in civic affairs, particularly those which have engineering construction or operation as their basis. He stated that prior to the recent conference of the Governors of the States on "The Conservation of Natural Resources," the presidents of the four national engineering societies formulated a series of broad resolutions which were presented at the conference as representing the opinions of twenty thousand American engineers. These resolutions were made the basis of the resolutions reported by the committee and unanimously adopted. It will be of interest to electrical engineers to know that this very important and unprecedented co-operation between the national societies in taking a fundamental part in an epoch-making conference was engineered by President Stott. Resolutions commending his action were passed at a meeting of the Past Presidents of the Institute and also by the convention. The question of government policy in connection with water power development and national forests received intelligent discussion. To what extent and under what conditions should the people (represented by the government) entrust the transmission of power from a natural source which belongs to them to a private monopoly? The suggestions along this line presented in the paper by Mr. F. G. Baum were

energetically criticised by all who took part in the discussion as favoring entirely too much the transmission company and not fairly conserving the public interests.

Greetings from the National Fire Protection Association were presented in the paper by Mr. C. M. Goddard. The property loss by fire in this country last year was one hundred and eighty million dolars, which is about fifty percent more than the value of our great fleet of battleships which is now in the Pacific. Mr. Goddard urges co-operation for mutual benefit in the endeavor to further reduce the fire hazard of electricity, "the safest illuminant and the safest source of power that we have." He proposes co-operation in words that may well be given a general as well as a particular significance. "Our interests lie in the same direction, we must travel along together and put up with each other's faults whether we will or not. Shall we not walk as companions rather than enemies? Neither of us has a right to all the good things, nor deserves all the bad things; let us share the good things we have and help each other with the bad things we must meet."

In "High Voltage Experiments at Niagara," Mr. R. D. Mershon finds that the critical point, above which, if the transmission voltage be raised, the loss into the air increases very rapidly, is lower than was indicated by the laboratory tests of Prof. Ryan, and also that the presence of moisture and dust or smoke increases the loss in a way which previous and less comprehensive tests had not shown. Fortunately, however, the conductivity and the cost of conductors, for transmitting power is such that the size which is most economical to use with a given voltage, as set forth in a paper presented by Mr. Mershon in December, 1904, is of sufficient diameter to make the loss into the air negligible at that voltage. The critical point at which loss begins is a little higher. If Nature had made the air much weaker, thereby changing the relation between diameter of wire and the critical voltage, the commercial limitation in power transmission, might be quite different. It is further found that the insulator loss with a wooden pin is greater than with an iron pin as the resistance of the wood is in series with the charging current.

Most of the three dozen papers relate to particular machines or problems or experiences. Among the educational papers one by Mr. M. W. Alexander presented a plan of teaching theory and practice alternately (the frequency being a few months) by the

Massachusetts Institute of Technology and the Lynn Works of the General Electric Company. Mr. Alexander, of the Electric Company, and Prof. D. C. Jackson, of the Institute, expect much better results than are obtained by the usual four years of school followed by two years of shop apprenticeship. Several members criticised the plan rather severely. It certainly possesses some valuable features as well as involving difficulties. With care the latter can probably be overcome. The results of this important deviation from ordinary methods will be awaited with much interest.

On the third evening of the convention about seventy-five of those interested in Institute Sections and Branches held a very animated meeting, discussing methods and results. Three hours was quite insufficient to enable all to talk who wanted to tell what they were doing. There are now more local organizations, including those in colleges, than there are states. The marked feature of the meeting was the earnest interest taken in the work. Local committees are scarcely less active and zealous than the directors and the general committees. There is an underlying loyalty to the central organization and a thorough spirit of co-operation. Local development has taken different courses in different places—which a broad policy has permitted.

An incident, personal to the writer, was the presentation to him by Dr. Sheldon of engrossed resolutions by the Board of Directors expressing appreciation of his services in connection with the Engineering Societies' building. The plan materialized during his administration as president—thanks to the wise gift of Mr. Carnegie—and he was in active relation to it as member of conference and building committee and as trustee until the expiration of his term of office last January. The formal resolutions recall the many pleasant and lasting friendships formed with his co-workers in bringing the building to its happy consummation.

The convention was permeated with an unusual interest in institute affairs and development. One member remarked that nothing so impressed him as the interest taken by the past presidents in attending the convention and having a meeting of their own for the discussion of Institute welfare. They underwent the double ordeal of getting up for a half-past-seven breakfast together and then being lined up by the local photographer.

CHAS. F. SCOTT

EUROPEAN PRACTICE IN DIRECT-CURRENT TURBO-GENERATORS

J. S. S. COOPER

British Westinghouse Electric & Manufacturing Company

COMPARED with the rapid advance made in the development of alternating-current generators for turbine speeds, the progress of the direct-current turbo-generator appears slow and halting. The designer of this class of apparatus has not been able as yet to satisfy the demands of the turbine builder for higher speeds and larger units, nor to entirely convince the station engineer that he is dealing with a reliable and trustworthy piece of apparatus. This state of affairs is by no means due to any lack of enterprise or ability on the part of the manufacturers, but rather to the inherent difficulties of the problem itself. The mechanical difficulties are chiefly due to centrifugal force, which limit the peripheral speed to about 16 000 feet per minute, and even at this speed there may be as much force as 2 000 pounds per pound of material. Extremely accurate balance must also be attained, and it is found that the old arrangements used in machines for engine speeds are not sufficient under the new conditions. Commutation is one of the chief electrical difficulties, mainly because the time available for the reversal of current in the short-circuited coils is exceedingly short. In addition to this, many makers have had a considerable amount of trouble from flashing over. Long cores and high speeds mean a large number of volts per coil, and thus a large potential difference between adjacent commutator bars. For this reason bad sparking is far more liable to result in flashes in turbine machines, which are remarkable for their long armatures, than in the ordinary slow-speed type with a comparatively short core length.

In spite of these difficulties, English and Continental firms have built a large number of direct-current generators for turbine drive, most of which are in successful operation to-day. Some of the methods which have been adopted by European manufacturers to overcome the various difficulties that have arisen, and produce a thoroughly commercial machine are given below.

THE FIELD SYSTEM

The field is commonly of quite special construction, being provided both with commutating poles and coils, and with a compen-

sating winding in slots in the pole face. The commutating poles produce a local field for the reversal of the current in the coil that is undergoing commutation, while the compensating winding is designed to prevent distortion of the main field by the reaction of the armature.* Both windings carry the main current, or a proportional part of it. Successful prevention of field distortion results in: (1) better commutation with fixed brush position; (2) less liability to flash-overs, as the voltage gradient is not concentrated at any point in the circumference of the commutator and the maximum voltage between any pair of adjacent bars is thus kept as low as possible, and (3) minimum iron loss in the armature. The use of slots for this winding makes it advisable to laminate at least the tips of the poles. The commutating poles, and the shanks of the main poles may be either laminated, or of cast or forged steel. The field sytem of a 1 000 kw four-pole, 1 500 r.p.m. generator is shown in Fig. 1. Laminated pole shoes are used, while the yoke and commutating pole are of cast steel, and the main pole shanks are steel forgings. Fig. 2 shows the unwound field system of a 135 kw four-pole ma-

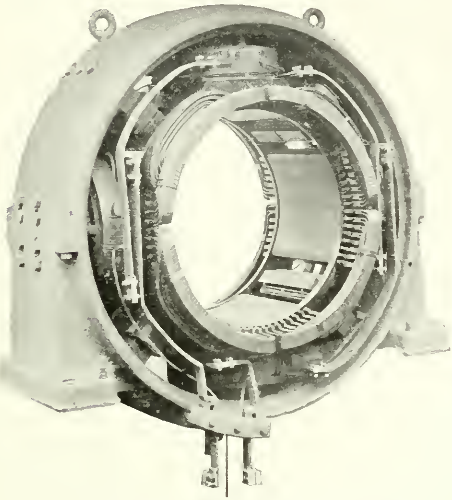


FIG. 1—FIELD OF 1 000 KW TURBO-GENERATOR (BRITISH WESTINGHOUSE)

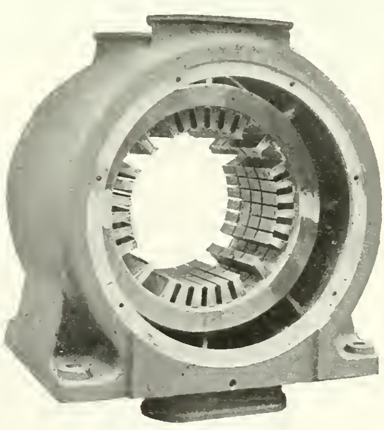


FIG. 2—FRAME AND CORE OF A 135 KW GENERATOR (BROWN BOVERI)

*See article on "Problems in Commutation" by Mr. Miles Walker in the JOURNAL for May, 1907, p. 284.

chine. In this machine all of the magnetic iron is laminated, and the cummutating poles are merely teeth standing more or less by themselves. Fig. 3 shows a similar stator, but with two poles, with the windings in place, the particular style of winding shown in these two photographs being in accordance with Deri's patents. These illustrations also show the method of ventilation adopted by most Continental firms.

ARMATURE

As compared with ordinary direct-current armatures, the armatures of turbine-driven machines are remarkable for their small diameter and relatively greath length. This is necessitated, of course, by the limitations imposed by the mechanical properties of the materials employed. The shaft frequently assumes a very large diameter on account of the long span between bearings, and especial care must be taken to avoid sudden changes of section and to provide fillets of ample radius at all shoulders. Tough steels of the nickel class are best adapted to withstand the arduous conditions of vibration and alternating stresses which are prominent in this work.

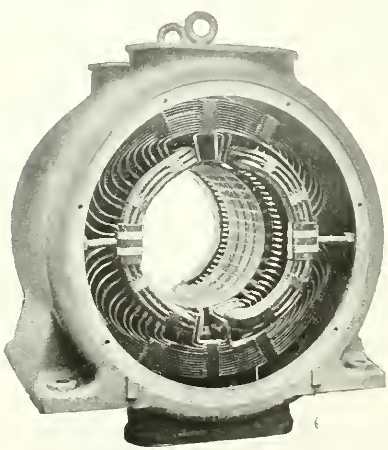


FIG. 3—FRAME, POLE PIECES AND WINDING OF A 135 KW TURBO-GENERATOR (BROWN BOVERI)

One of the most difficult of the mechanical problems is the satisfactory holding of the end windings. Steel band wire and steel coil supports are not satisfactory here, as they are subject to excessive eddy current and hysteresis losses as they run through the leakage fields. Brass or bronze brackets are used to support the coils, which are held down by bands of phosphor bronze wire, of a diameter of about 0.08 inch, built up to a depth of as much as an inch in some cases. The edges of each band are sweated solidly together and further secured every few inches by tinned copper strips wound in with the wire and sweated down afterwards.

Inside the slots, the coils are held by wedges. The form of slot used in a turbo-exciter designed to work up to 3 600 r.p.m., with an armature diameter of 11⅝ inches, is shown at *A* in Fig. 4. This

type of wedge is quite satisfactory for small machines and narrow slots. For larger machines, however, the form *B* is by far the stronger construction, but has the disadvantage that the coil cannot be completely insulated before being placed in the slot.

The armature should be balanced both before and after winding. For balancing, either screws may be inserted in one or more sets of tapped holes in the periphery or in one of the shrink rings, or a groove may be turned in some similar place and suitable wedges fastened in where needed. In any case the balancing device should be in duplicate, one at each end of the armature, so as to secure running as well as static balance. All insulating materials must be solid, well packed and unaffected by heat, as otherwise movement of the copper will result and the balance will be lost.

The ventilating arrangements employed in the armature differ but little from those used in ordinary small direct-current machines. The ventilating ducts are fed either from holes punched near the shaft, or by means of a shallow open spider. Except from the standpoint of cost, the latter is to be preferred, as it affords an opportunity for magnetically isolating the shaft, and thus preventing additional eddy curent. Some kind of fan is often fastened to the armature to improve the cooling conditions. In Fig. 13 the fan is seen between the commutator and the winding, while in Fig. 10 vanes are placed in the commutator shrink rings.

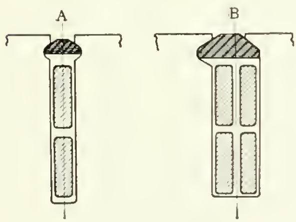


FIG. 4—ARRANGEMENT OF SLOTS AND RETAINING WEDGES FOR TURBO-GENERATOR ARMATURES

Besides the above mentioned mechanical features, this class of armature has several electrical peculiarities. As has been already explained, both length and speed are high, so that each coil cuts a very large amount of flux per second, and is thus the seat of a relatively high e.m.f. Only a few conductors are necessary, and correspondingly few commutator bars. Thus the mean voltage per commutator bar will be high, while the time of commutation will be short, so that commutation troubles and flash-overs are to be expected unless special provisions are made to overcome them. A slightly increased thickness of mica is often employed for these reasons. It has also been proposed to obviate these difficulties by inserting, between each pair of ordinary bars in the commutator, another bar of intermediate voltage, but not intended to carry the

main current. One suggested method is to take a tap from the rear end of each armature coil and connect it to the intermediate commutator bar as shown in Fig. 5, where the auxiliary winding is indicated by dotted lines connecting the rear ends of the coils to bars *2, 4, 6*, etc. The voltage of bar *2* is, of course, half-way between those of bars *1* and *3*, but bar *2* does not carry the main current of the machine.

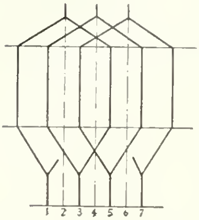


FIG. 5—AUXILIARY ARMATURE WINDING WITH TAPS TAKEN FROM REAR OF ARMATURE

A clever modification of this idea has been suggested by Mr. Miles Walker, who has embodied it in a 1 000 kw machine built by the British Westinghouse Company. Half the induction of one coil is obtained, not as above by going once through the core, but by going twice through half the core. This is shown in Fig. 6, where the core is divided into two parts, *A* and *B*. The main winding runs right through as usual, and is connected to commutator bars *1, 3, 5, 7*, etc., while bars *2, 4, 6*, etc., are connected to the special winding shown by dotted lines. This winding, of small cross-section is tapped off the main conductors in the space *C*, and passes to the proper slot by involute connectors in this space. It is subject only to the induction of the part *A* of the core, so that there is between bars *1* and *2* just half the voltage that there is between bars *1* and *3*. It is obvious that this idea could be extended, and that by dividing the core into three or more parts, several intermediate bars could be inserted, thus dividing the voltage between the main bars into any

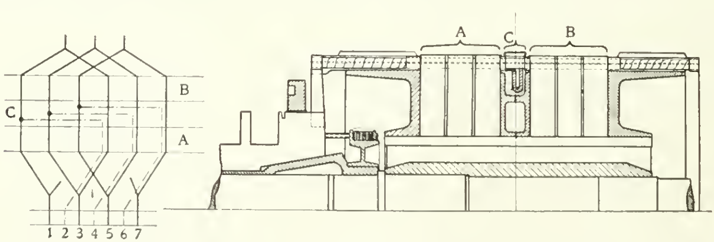


FIG. 6—CONNECTION DIAGRAM AND SECTION SHOWING AUXILIARY WINDING (MILES WALKER)

number of equal parts. The insertion of these intermediate bars in the commutator not only improves the commutation, but greatly diminishes the chance of a spark holding across the mica and developing into a flash-over. At the same time the compensating winding maintains an even distribution of flux and therefore of voltage, and

prevents the voltage between any two bars from rising much above the mean value.

COMMUTATOR AND BRUSH GEAR

In the commutator and brush gear, machinery must be provided for two purposes, the *collection* and the *commutation* of the current. For collection it is necessary to keep sufficient brush surface in continuous contact with the commutator. In commutation the current in each coil must be reversed every time the corresponding commutator segments pass under a brush. It has been seen how the armature and field are designed to assist in this process. All that is now necessary to insure sparkless reversal of the current in the short-circuited coil is to keep a carbon brush in contact with the commutator at or near the neutral line. It is only recently, however,

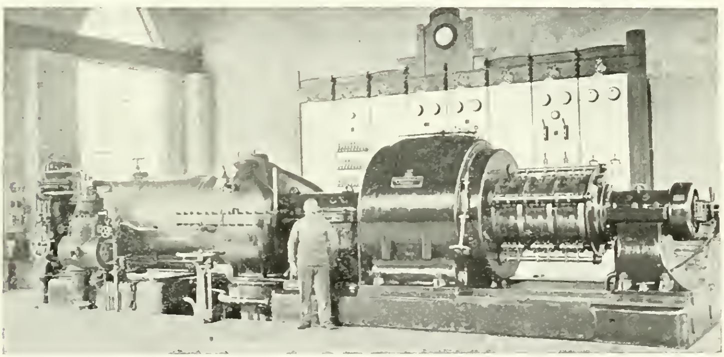


FIG. 7—1 000 KW, 550 VOLT, 1 250 R. P. M. TURBO-GENERATOR (BROWN BOVERI)

that this has been satisfactorily accomplished. No matter how well balanced an armature may be, at high speeds there will always be a slight vibration of high periodicity at right angles to the axis. To keep a carbon brush always in contact with the cylindrical surface of a commutator at economical speeds is thus all but impossible. Hence for a long time metal brushes have been considered unavoidable for direct-current turbo-generators. Tangential brushes of hard copper foil and bundles of brass wire have been used, the natural elasticity of which has enabled them to follow the movements of the commutator without movement of the holder. In order to increase the surface, Messrs. Parsons have turned grooves in the commutator into which the wires could fit. The British Westinghouse Company, as well as Messrs. Brown Boveri, have employed a

small graphite brush in front of the main laminated copper brush. The graphite assists in commutation (not appreciably in collection) and provides lubrication for the other brushes. These auxiliary brushes can be seen in Fig. 7, which shows a Brown Boveri 1 100 kw, 550-volt 1 250 r.p.m. machine.

Metal brushes are all more or less subject to certain troubles. For one thing they are of too low contact resistance to materially assist commutation. Before the advent of the compensating winding, it was the custom of Messrs. Parsons to supply an automatic brush shifting gear, actuated by the pressure of the steam in the steam chest. Even now it is not always an easy matter to obtain sparkless operation with metal brushes at all loads with fixed brush position. Again the wear of both brushes and commutator is excessive, and constant attention is needed, nor can this be cured by the usual device of cutting out the commutator mica near the surface. The rapid wear of the brush necessitates frequent feeding forward. At the same time the brush is more worn on its lower edge, so that the upper edge is apt to stick out beyond the point at which contact is desired. It is then necessary for the attendant to trim off the tip of the brush, and then the whole cycle must be repeated. It is impossible to know just how many commutator segments will be covered by brushes under these conditions, so that burning due to over and under-commutation is not to be wondered at. All these circumstances conspire to destroy the brush at the maximum possible rate, and it is found that brush renewals often amount to a very considerable figure per kilowatt generated. Cost of brush renewals as given by two engineers who were operating 900 and 1 000 kw generators of different makes, was 0.012 cents and 0.006 cents per kw-hour generated, i. e., for the 900 kw machine the cost was 10.8 cents per hour and for the 1 000 kw, 6 cents per hour, assuming full-load. This question of wear is then of the greatest importance, and will doubtless be the one on which metal brushes will finally be condemned.

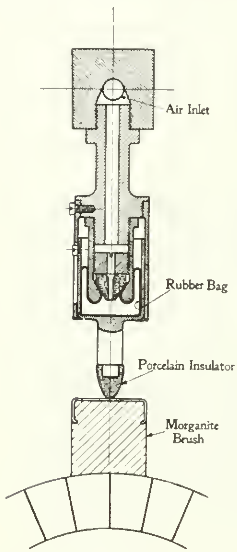


FIG. 8—LONGITUDINAL SECTION THROUGH PNEUMATIC BRUSH HOLDER (MORGAN CRUCIBLE COMPANY)

The Morgan Crucible Company, (London), whose graphitic and other brushes offer a valuable choice to the designer, has intro-

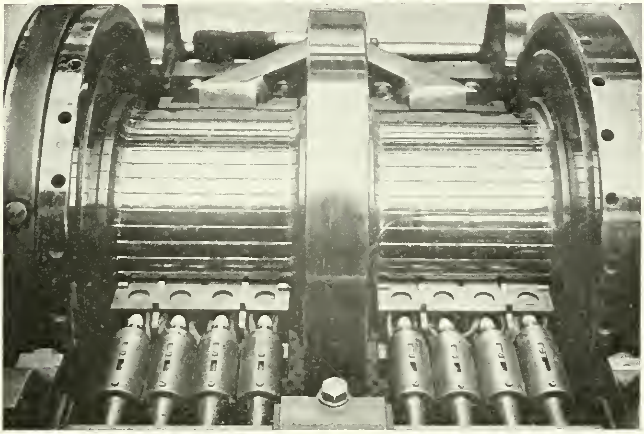


FIG. 9—COMMUTATOR OF 250 KW PARSONS TURBO-GENERATOR AT ALDERSHOT CAMP STATION, FITTED WITH MORGAN PNEUMATIC BRUSH HOLDER AND MORGANITE BRUSHES

duced the type of holder shown in Figs. 8, 9 and 10. This is designed to keep a "Morganite" (graphitic) brush continuously in contact with the commutator. Pneumatic pressure takes the place of any spring device, about three pounds per square inch being employed. Air pressure is kept up by a hand pump, and is stored in the reservoirs seen on the right in Fig. 10. Leakage is minimized by the rubber bag shown in cross-section in Fig. 8. The pressure is applied in the center of the brush, which is enclosed in a box type sliding holder. All current is carried by ample shunts, and the porcelain tip through which the air piston presses on the carbon, saves the working cylinder surface from the action of the current.

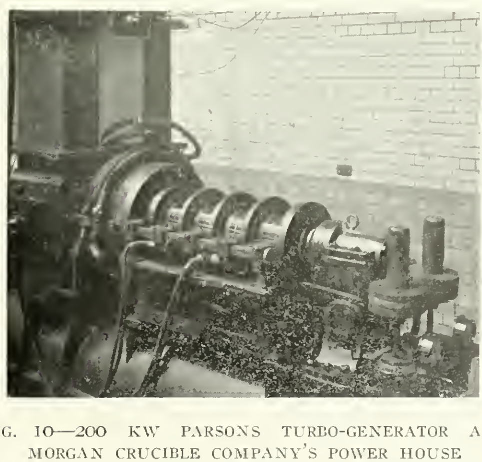


FIG. 10—200 KW PARSONS TURBO-GENERATOR AT MORGAN CRUCIBLE COMPANY'S POWER HOUSE

It is claimed that the lightness of the moving parts and the resilience of the air enables the brush to follow the liveliest movements of the commutator surface. The excellent condition of the commutator in

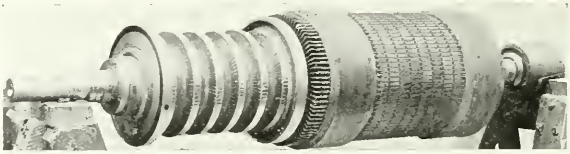


FIG. 11—ARMATURE OF 200 KW, 500 VOLT, 3 000 R. P. M. TURBO-GENERATOR WITH RADIAL COMMUTATOR (BRITISH WESTINGHOUSE)

Fig. 10 is a good advertisement of the success of this brush-gear on a 4 000 r.p.m. generator.

Instead of attempting to keep the brush in contact with the cylindrical surface of the commutator, the British Westinghouse Company have avoided the difficulty by abandoning the curved surface, and pressing the brushes against the flat faces of a series of discs. The method of construction is shown in Figs. 11 and 12. The armature of a British Westinghouse 200 kw, 500 volt, 3 000

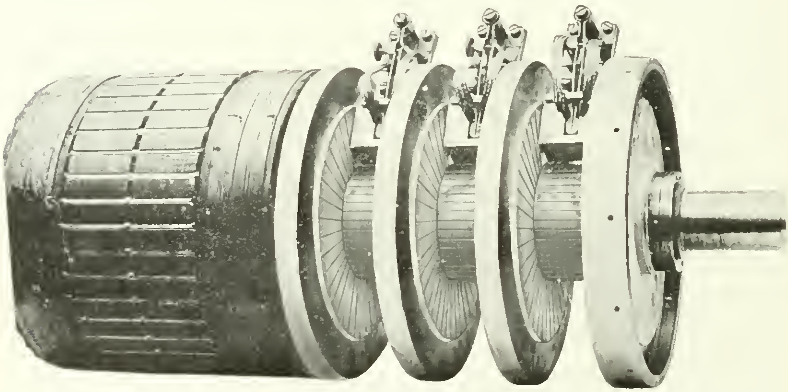


FIG. 12—ARMATURE OF EXCITER FOR TURBO-ALTERNATOR (BRITISH WESTINGHOUSE)

r.p.m. machine is shown in Fig. 11, with a "radial" commutator of five grooves. A small low-voltage exciter armature is shown in Fig. 12, together with part of the brush-gear. It may be seen that the brushes are not quite in the radial position, and are wedge-shaped to conform to the radial commutator segments. Pressure is applied only between the two brushes in each groove, so that if the armature moves endways the springs do not oppose the movement of the brushes. High conductivity graphitic brushes are used of

good lubricating quality, such as "Morganite," and the current is carried from them by heavy braided copper shunts.

The wear on the radial commutator and its brushes is remarkably small. The first machine of this type has now been in service over eighteen months, and no grinding or turning of the commutator has been needed. The operation is entirely satisfactory, there is no difficulty in maintaining contact, as any axial movement of the armature is slow and easily followed. The only objection to the radial construction is one of expense, as both commutator and brushgear are slightly more costly than the usual type. But for large powers or high speeds the expenditure should be fully justified, and will be found to be amply repaid in decreased attendance and renewals. This construction places the direct-current turbo-generator in the

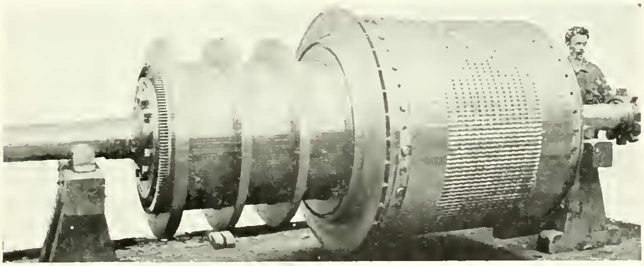


FIG. 13—ARMATURE OF 1 500 KW, 550-600 VOLT, 1 000 R. P. M. TURBO-GENERATOR AT THE MUNICIPAL GAS AND ELECTRICITY WORKS, ROTTERDAM (BROWN BOVERI)

same class with the slow-speed engine-type generator so far as reliability and satisfactory operation are concerned.

In Fig. 12 may also be seen, at the top of each disc of the commutator, the mica-insulated steel shrink ring, and on the outer one the groove for the balance weights. In Fig. 11, however, the only shrink rings visible are on the first and last discs, in which balancing grooves are again to be seen. The intermediate shrink rings are replaced by bands wound one in the bottom of each groove and completely insulated on all sides. The reason for this is that this machine is designed for 500 volts. At this pressure, unprotected shrink rings are a source of danger, as a flash might occur from brush to brush through the ring. This is an additional advantage of the radial type of commutator, as this covering of the shrink ring is not easily accomplished on a smooth type. The question of flash-overs at higher voltages is in any case one of commanding importance, and it is frequently the criterion that decides the number of poles in a

machine. For instance at 2 500 r.p.m. the diameter of commutator is so limited that a four-pole machine will not give enough distance between brush holders for 500 to 600 volts. The designer is thus driven to a two-pole design unless he doubles the length of the com-

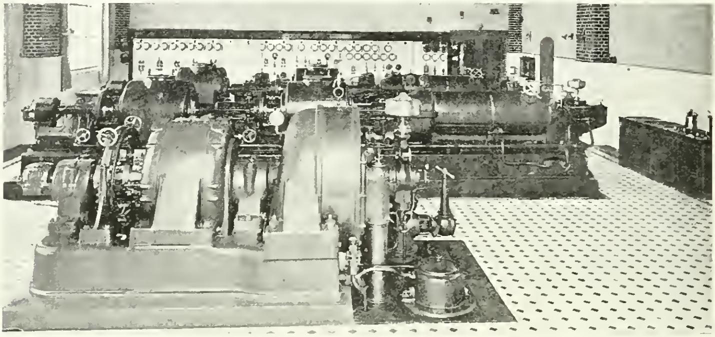


FIG. 14—VIEW OF ENGINE ROOM OF HILDESHEIM ELECTRICITY WORKS, SHOWING DIRECT-CURRENT TURBO-GENERATOR SET IN FOREGROUND (A. E. G.)

mutator, and places all positive brushes on one-half and all negative brushes on the other. At 200 to 250 volts, however, the most satisfactory design will have four poles.

The shrink rings on a large commutator of the ordinary type are shown in Fig. 13, which shows the armature of a Brown Boveri

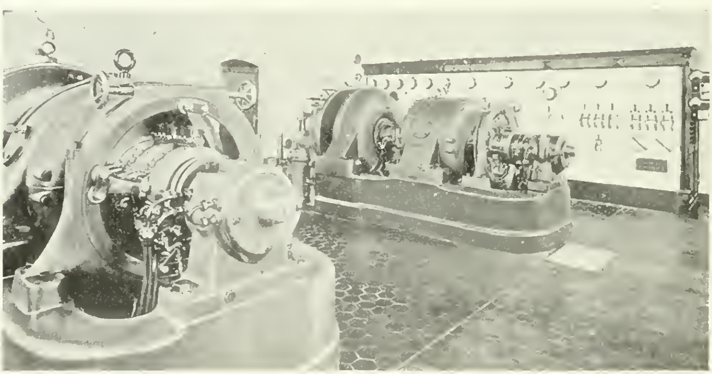


FIG. 15—VIEW OF TURBO-GENERATOR SETS IN THE STATION OF THE OLDENBURG ELECTRIC SUPPLY COMPANY (A. E. G.)

1 500 kw, 550 to 600 volt, 1 000 r.p.m. turbo-generator installed in Rotterdam. This figure also shows the balancing grooves and screws, the fan between armature and commutator, and the solid shields over the windings. Shrink rings of the same kind are also

to be seen in Figs. 14 and 15, which are installations by the Allgemeine-Elektricitats-Gesellschaft, of Berlin. Here is shown as well, the enclosed type of field adopted by this firm, also the very substantial brush holder construction. A comparison between this and Fig. 7 will show the different methods adopted for providing the very necessary rigidity of brush gear.

The brush gear adopted by the British Westinghouse Company is illustrated in Fig. 16 as applied to the seven-groove radial commutator of a 1 000 kw generator. The brush arms take the form of very substantial iron castings, supported between two cast iron rings, and make an unusually stiff construction. The brush holders slide into grooves machined in the arms in such a way that they

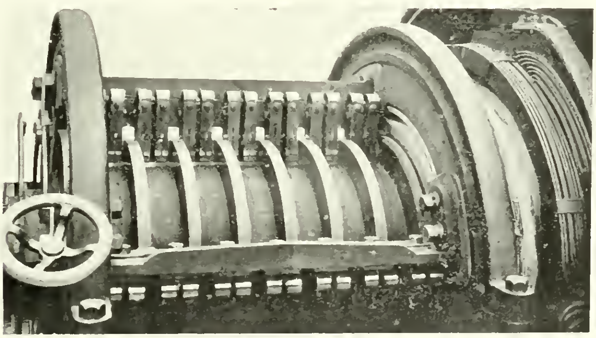


FIG. 16—COMMUTATOR AND BRUSH GEAR OF 1 000 KW, 500 VOLT, 1 500 R. P. M. TURBO-GENERATOR (BRITISH WESTINGHOUSE)

can only be removed in a radial direction. The brushes are held by springs against the smooth face of the brass holder which is mounted so that the rotation of the commutator assists the springs and keeps the brushes firmly in place. Each holder supports two brushes which are pressed apart against opposite sides of their groove by means of a separate double spring. The tension of this spring is applied by a small screw with milled head, which presses the two sides apart. The two brushes can thus move to and fro as a whole, while the spring turns on a pin at the top, and so maintains its full effect in all positions. Any movement of the commutator will, however, be small, so that ordinarily the spring will hardly need to move on its pivot. No current is carried by either set of springs, so that weakening or loss of temper need not be feared. The low brush wear and the high durability of all parts bring down renewal and attendance costs to a minimum.

ELECTRIC RAILWAY ENGINEERING—VII

SELECTION OF CAR EQUIPMENT

F. E. WYNNE

IN order to choose the correct car equipment for a proposed service, it is essential for the engineer responsible for such selection to have at hand certain accurate and complete data. The necessary data may be classified under three heads:

Physical characteristics of the road,
Car types, weights and dimensions,
Conditions of operation.

PHYSICAL CHARACTERISTICS OF THE ROAD

The principal physical characteristics of a line, as affecting car service, are best obtained through a careful study of the map and profile in connection with a personal inspection of the territory to be served. In this way the total length of the route, and its division into city, suburban, and interurban sections, is readily obtained. The lengths, amounts and locations of grades and curves can also be noted. The regular stopping points, switches, turnouts, grade crossings, branch lines, junctions with other roads, double track sections, cross-overs and right of way are shown by this map. This information should be accompanied by a statement of track gauge, rail weight and maximum speed which the roadbed will stand.

CAR TYPES, WEIGHTS AND DIMENSIONS

Before choosing a car equipment, the type of car, whether single or double truck, open or closed, should be known. The weights of car body and trucks and the seating capacity of the car should be given. The general dimensions of the car body, including length, width and height, the wheel base, distance between truck centers, wheel diameter and width of truck bolster should be available. Similar information relative to trailers is necessary if a trailer service is to be operated. If the cars are to be equipped for multiple-unit control, it becomes necessary to know whether side doors or end doors with vestibules are to be used and a dimensioned drawing of the car under-framing is required. These data are necessary for determining the layout of apparatus on the car.

The total car weight is made up of the following items, which are usually segregated: Car body, car trucks, electrical equipment,

brake equipment, heaters and load. In estimating the load, a fair average may be obtained by taking the seating capacity of the car at 140 pounds per passenger.

The general dimensions of the car body in connection with wheel base and truck centers determine the minimum radius of curvature permissible, the clearance at under-crossings and the clearances on each side of the track at curves. The wheel base and width of truck bolster limit the size of motor which may be mounted on the truck.

CONDITIONS OF OPERATION

The operating conditions are usually given by a statement of the running time between terminals and the time for each section, number of stops in each city, suburban, and interurban section, lay-over at each terminal, headway or time interval between successive trains in the same direction, daily hours of service, lengths of stops, and the definite location of as many regular stopping points as possible.

With the above information known, the schedule speed for each section may be determined from the length of section and time allowed for traversing it.* For the city sections there is little choice of speed because interurban cars generally enter cities over tracks on which local lines operate and the local schedule limits the speed of the interurban cars. This city speed is most frequently between eight and twelve miles per hour, even though the interurban cars may stop for passengers not oftener than once per mile. Occasionally a case is found where the city speed may be as high as fifteen miles an hour, as when the interurban cars enter over streets having very light traffic so that a practically clear track is assured. In such cases the schedule is limited chiefly by the maximum speed which is permitted by city ordinance.

On suburban sections the schedule speed is most frequently from fifteen to twenty miles per hour with from one to three stops per mile. The local interurban schedule speeds most common are those between 28 and 35 miles per hour with stops from 1.5 to five miles apart. The interurban schedule speed for limited cars may be anything within a wide range, the lower limit of which overlaps the local interurban speeds, limited cars on some roads making as frequent stops as local cars on other lines. At present the maximum

*Schedule speed = miles distance ÷ hours time.

limited interurban schedule speed is 54 miles per hour on a 36 mile run.

Having determined the several schedule speeds for the desired service, it becomes necessary to consider these speeds in conjunction with the car data. It is at this point that data on operating roads and experience in equipment selection are required. From a knowledge of the schedules which are being made in actual service by certain equipments, together with the car weight and frequency of stops, it is possible to choose a trial equipment for the case under consideration. It is next necessary to pick out the gear ratio for the trial equipment. This may be approximated as follows: The schedule speed on the interurban sections of a road is usually the highest in proportion to the length of run and is therefore the determining factor in the choice of gear ratio. The ratio of schedule speed to ultimate speed on level track will vary between 60 and 80 percent for runs from two to six miles in length. From this ratio the ultimate speed for a specific service is readily determined. Then for the trial equipment that gear ratio which will most closely approximate this ultimate speed may be chosen.

The suitability of the trial equipment for the desired service may be found by the use of speed-time and power curves from which the heating of the motors on each section is calculated. These curves may show several undesirable conditions.

The gear ratio may be such that between the maximum possible schedule speed and the desired schedule speed there is not sufficient margin for overcoming unusual delays, or this margin may be greater than is necessary or advisable. In practical working it should be such that the equipment may occasionally be forced under emergency conditions to make the trip in from five to fifteen percent less actual running time, exclusive of standstill time, than that which is allowed for the regular service. The necessary amount of this speed reserve for any case is dependent upon local conditions.

It may be found that the motors selected are too small or too large for the service, the indication of motor capacity being given by the square root of the mean square current and equivalent voltage for the run. The square root of the mean square current for an entire run made up of several sections on which the service differs is found by averaging the current squared values on a time basis and taking the square root of this average. For example, on the city, suburban and interurban sections of a certain road, the square root of the mean square current values are respectively 70 amperes

for 20 minutes, 63 amperes for 15 minutes and 52 amperes for one hour and 15 minutes.

Then $70^2 \times 20 = 98\,000$ amperes^2 minutes

$63^2 \times 15 = 59\,600$ " "

$52^2 \times 75 = 202\,400$ " "

Total for 110 minutes $= 360\,000$ amperes^2 minutes.

Then the square root of the mean square current for the entire trip is $\sqrt{360\,000 \div 110} = 57.2$ amperes.

The equivalent voltage for the entire trip may be obtained by averaging the iron losses for the several sections, introducing the time element in the same manner as with the current values and finding the voltage which will produce this average iron loss when the motor is taking the square root of the mean square current found for the entire trip. In city and suburban service the equivalent voltage is generally found to lie between 200 and 300 volts and in interurban service between 300 and 400 volts. Therefore, the continuous current motor ratings for 300 and 400 volts give ample indication of the motor's capacity for each class of service. On the larger motors additional ratings for the motors when run open are sometimes given, since open operation of the motors in elevated service is often permissible.

In motor capacity there should be a reserve of from five to fifteen percent in order to insure operation under emergency conditions without damage to the equipment. As with the speed reserve, the necessary margin in motor capacity must be determined from the consideration of local conditions. Of course the amount of reserve in either capacity or speed is to a certain extent inherent in the equipment because ordinarily the equipment must be chosen from a line of standard sizes, it being obviously impracticable for the manufacturer to build an equipment to exactly fit every individual case which arises. But even so, it is possible to regulate the amount of margin to some extent by changing the gear ratio.

If the trial equipment is found to be correctly geared for the service but to be of unsuitable capacity, the proper motor is indicated by the square root of the mean square current value found from the trial curve. This is so because the square root of the mean square current values for a given service and car with various equipments are approximately the same. Hence, by comparing the value found from the trial curve with the rated capacities of the available motors, the motor most suitable for the service may be

obtained. Further calculations are necessary to determine the proper gear ratio, best rate of acceleration, amount of heating and power consumption, with the equipment finally chosen.*

In a service where a single motor car at times handles one or more trailers, it is rarely possible to maintain the same schedule with trailers as with single motor cars. In case the maintenance of single car schedule speed with trailers is possible, the equipment will be worked much harder when operating with trailers because of the increased weight to be handled. The reasonable method of operation is most frequently found in allowing a trailer service only under the condition of a reduction in the schedule speed. This makes it possible to minimize the size of car equipment and at the same time insure it against abuse from overloading.

Except where electric roads are operated on a steam road basis with definite stops, it is impossible to calculate the speed-time and power curves for the entire line. Even in such cases it is rarely necessary to do so, for the labor of selection may be materially decreased by choosing runs which are typical for each section and the results yet be within the limits of accuracy fixed by general conditions. In each natural division of the line, city, suburban and interurban, the stops will be spaced with a fair degree of uniformity so that the average length of typical run for that section may readily be found.

The profile must be consulted in order to determine the average grade for the section. If the grades are short, easy and so located that they may be descended without brake application and the terminals have approximately the same elevation, the line may be considered level without serious error. If, however, there is a considerable difference between the elevations of the terminals and the grade from one terminal to the other is fairly continuous, the average grade between terminals should be calculated and used for the typical run.† If the grades are long, steep and inclined in both directions, it becomes necessary to sectionalize the line further according to the grades and select a typical run for each grade section.

The effect of curves on speed is largely dependent upon track construction and location. Curves of such radius that they may be rounded at schedule speed may be neglected. Curves which require limiting the speed to one-half the schedule speed or less may be

*See the JOURNAL, Vol. III, pp. 256-7, 372 and 378-9.

†Percent average grade = ft. difference in elevation × 100 ÷ ft. distance between terminals.

taken as equivalent to a stop. A sharp curve at the foot of a long grade will often reduce the speed by requiring the cars to descend the grade under brakes for the sake of safety. If a line is very crooked, allowance for curvature in the typical run may be made by finding the average curve. The average curve may be found by dividing the sum of the products of the length and degree of curvature for the individual curves by the total length of line.

While the track gauge is ordinarily standard, four feet 8.5 inches, it is not unusual to find electrifications where the track gauge is not standard. These cases are chiefly proposed electrifications of existing narrow-guage steam lines in this country and foreign work, including both proposed roads and electrifications of existing roads. Numerous narrow gauges are in use; the principal ones being three feet, three feet six inches and one meter. The gauge often limits the capacity of equipment which may be installed on a car.

Sources of delay which are frequently overlooked are turnouts and grade crossings with other lines. It is best to consider these as extra stops for all local trains. The first may sometimes be neglected in limited service where the inferior train is required to clear the main track by an ample margin before the limited is due. The extra stops for turnouts are absent on double track roads and therefore such roads may permit faster schedules than single track roads with an equal number of traffic stops and the same equipment.

The total capacity of equipment required is often such that choice must be made between a two-motor and a four-motor equipment. On a reasonably level line with ordinary speeds and not too frequent stops, the two-motor equipment offers the advantages of lower maintenance and lighter, cheaper and more efficient equipment. The double equipment is more efficient because large motors have a higher efficiency than small ones. The equipment maintenance charges will be less with double equipments because expense of maintenance increases with increase in the number of motors. If, however, the service is such that operation on heavy grades is necessary or high acceleration is essential to the maintenance of the schedule, an advantage will be found in the greater adhesion possible with a quadruple equipment. This advantage is also pertinent to equipments for handling a trailer service. From this it is seen that the question of double or quadruple equipments is a part of every case of equipment selection.

With high powered interurban cars, the city sections are operated most economically with the motors connected in series-multiple. This is often best for the suburban sections also. Although not regularly provided for, cases may be found where it is justifiable to introduce the additional complication necessary for connecting all four motors of a quadruple equipment in series, in order to have such connection available for city running.

In selecting equipments for city systems, the conditions of operation are so varied and often so difficult of determination that it is necessary to rely very largely upon experience and data from existing similar systems, rather than upon speed-time and power curves based on assumed conditions. Such selection, therefore, becomes a matter of judgment in utilizing available data rather than a matter of exact calculation according to rules.

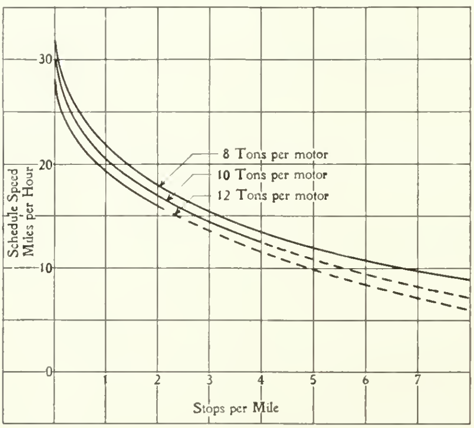


FIG. 1

Data for use in selecting equipments may be compiled and presented in various convenient forms. Tables may be constructed giving the schedule speeds for an equipment with several gear ratios on various lengths of run and with different weights of car. This same data may be presented by a series of curves such as shown in Fig. 1. In this figure the speeds at zero stops per mile are the ultimate speeds on straight level track. The dotted portions of the curves indicate that the motors would be worked above their capacity under the conditions corresponding to the dotted sections. The information for any particular car, equipment and gear ratio may be given more in detail by a curve of the form shown in Fig. 2, which is self-explanatory.

If the equipment to be selected is for multiple operation unit switch control must be used. With this control the acceleration may be hand-controlled or automatic.* Hand-controlled acceleration with

*See article on "Control of Cars and Trains Operated by Direct Current," by William Cooper, in the JOURNAL for March, 1906, p. 127.

the unit switch system is productive of the same results as the ordinary hand-operated controller. The automatic acceleration may be arranged to give constant current per motor, constant current per car or the current per car may be different with the series and parallel connections of motors, although held constant in each position. Automatic acceleration is best adapted to roads where there are no heavy grades or other features which make it necessary at times to use starting currents much greater than the average for which the

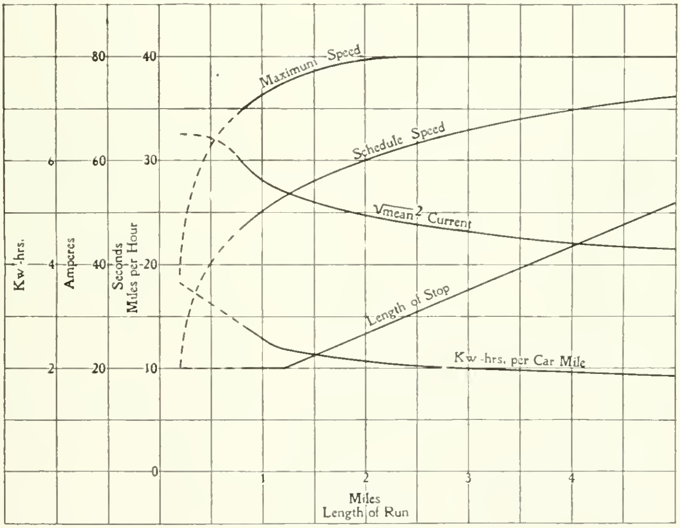


FIG. 2

apparatus should be adjusted. Its application must be limited in this way because excessive current at starting will prevent the control from notching up and will result in burned out resistances. It is possible to overcome this difficulty by providing a switch for temporarily short-circuiting the limit switch where the heavy starting currents are required. There is, however, one objection to this device, in that it provides an opportunity for the abuse of the equipment.

A comparison of the power consumption and heating, with the three methods of automatic acceleration mentioned (Table I) shows that there is practically no difference between them in so far as heat-

ing goes. On short runs, of three-fourths of a mile or less, the acceleration with constant current per motor is less economical of power than either of the other methods which are about on a par with each

TABLE I.

Length of Run—Miles.	Constant Current per Motor.		Constant Current per Car.		Ratio of Series Car Current to Multiple Car Current = ¾.	
	Sq. rt. mn. sq. current.	Kw.-hr. per car-mile.	Sq. rt. mn. sq. current.	Kw-hr. per car-mile.	Sq. rt. mn. sq. current.	Kw-hr. per car-mile.
0.5	74.0	3.47	73.5	3.31	72.5	3.19
1	68.1	2.64	69.0	2.66	67.8	2.67
2	60.9	2.18	60.8	2.13	60.0	2.16
3	57.4	2.05	57.6	2.04	57.0	2.05
4	56.0	2.07	56.1	2.08	55.9	2.07
5	55.0	2.10	54.6	2.09	54.9	2.11

other. On longer runs the power consumption is practically the same with all three methods. The constant current per car method has an advantage over the constant current per motor method in that the

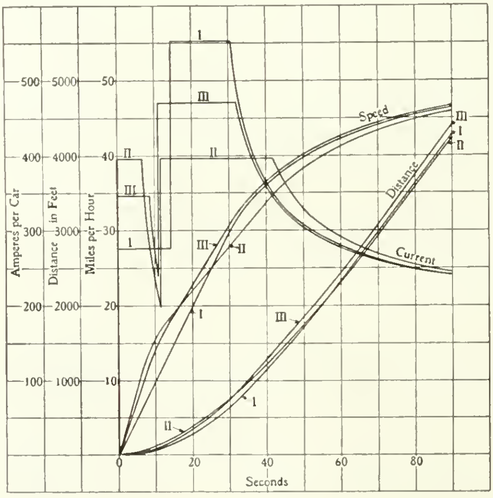


FIG. 3

I—Constant current per motor; II—Constant current per car; III—Ratio of series car current to multiple car current = ¾.

maximum line current and demand on the power house are reduced. The third method has the same advantage over the constant motor current method in less degree and also has an advantage over the

constant current per car method in that the motor current in the parallel position is greater and it is therefore possible to use it on a hilly road with less danger of trouble from failure of the control to notch up through the parallel steps. In any case, by means of a relay in the motor circuit, it is possible to prevent the control from connecting the motors in parallel until the current has fallen to a value which permits notching up through the parallel steps.

A good indication of the relative values of currents, accelerations and distances on level track by the three methods may be obtained from Table II. and Fig. 3.

TABLE II.

	I Constant Current per Motor	II Constant Current per Car	III Ratio of Series Car Current to Mult. Car Current $= \frac{3}{4}$
Max. current per motor–series	138	198	174
" " " " mult.	138	99	118
" " " car–series	276	395	348
" " " " mult.	552	396	472
Acceleration series	1.0	1.8	1.6
Acceleration mult.	1.0	0.6	0.8

It may be seen that the third method has further advantage over the second method because of the smaller motor current in series. Generally the third method will be found most satisfactory for automatic acceleration.

ALTERNATING-CURRENT POTENTIAL REGULATORS

GEORGE R. METCALFE

THE accuracy of regulation of the current furnished from a central station is the chief criterion by means of which the excellence of the service is judged by the public; and, as incandescent lamps are very sensitive to even slight changes in voltage, it is imperative that very close voltage regulation be provided in order to furnish a thoroughly satisfactory lighting service. In direct-current systems approximate uniformity of voltage is obtained through the inter-connection of the distributing mains, by which heavily loaded feeders are relieved to a certain extent by adjacent feeders connected to the same network. The interconnections of the feeders and mains tend to establish a uniform pressure over the whole system, and the voltage can then be adjusted by varying the potential on the station bus-bars. In large direct-current systems, however, where there is considerable difference in the lengths of the feeders, it frequently becomes necessary to install two or three sets of bus-bars, each carried at a different potential, between which the feeders are divided according to their lengths, the shorter feeders with the lower drop being connected to the buses of lower potential, and the longer feeders to those of higher potential. In some cases, very long feeders are run in series with boosters in order to maintain the required voltage at the points of distribution.

The problem of voltage regulation in alternating-current systems is much simplified owing to the fact that potential regulators may be used. The modern practice in alternating-current distribution is to maintain a constant potential on the station bus-bars so that the feeders connected to them are all supplied at the same voltage. In order to secure good regulation throughout the whole system, a potential regulator is provided for each feeder, by means of which the voltage is maintained constant, irrespective of the load or length of the feeder.

The voltage drop on any feeder depends upon its location, sectional area and length, and upon the amount and power-factor of the load that it carries. In comparing the loads on different feeders, it is also necessary to consider the time-load curve on each feeder as, even when the average loads on each are approximately equal, the

time-load curves may vary widely. Owing to these variable conditions of load it is apparent that good regulation can be provided only by independent compensation for the voltage drop on each feeder, and this function is admirably fulfilled by the potential regulator.

TYPES OF REGULATORS

There are two types of regulators in general use: (1) the induction type regulator, and (2) the step-by-step regulator. The single-phase induction regulator effects changes of voltage by altering the position of a coil in a magnetic field, thereby changing the magnetic flux passing through the coil; and the step-by-step regulator effects a similar result by cutting in or out, by means of several taps, sections of the winding of a regulating transformer. The polyphase induction regulator differs in principle from the single-phase regulator, as explained later. The single-phase regulators are used on feeder circuits supplying electric lights, and the polyphase on mixed lighting and power circuits, and in connection with rotary converters.

All alternating-current potential regulators are, in effect, variable-ratio transformers, and because they are transformers rather than consumers of energy it follows that the product of the volts and amperes on the feeder side of the regulators is equal to the product of the volts and amperes on the generator side, less a small loss in the regulator itself. As these regulators have a high efficiency, and transform only a small proportion of the total energy of the circuit, the effect of the regulator losses upon the system is very slight. For example, regulators commonly have capacities such as to give an increase or a decrease of ten percent of the generator voltage, and they, therefore, handle but ten percent of the energy of the circuit. If the regulators have an efficiency of 95 percent, the loss of energy on the whole system due to the regulators will be but one-tenth of five percent, or one-half of one percent.

INDUCTION TYPE REGULATORS

The induction regulators here described are of a type that has been recently developed and involve a number of novel points of interest. In general construction they resemble induction motors. A feature of special importance is their adaptability to automatic operation, whereby a constant potential may be maintained on a feeder without any attention on the part of the station attendants.

Single-Phase Induction Regulators—Regulators of this type consist of a regulating transformer having two separate and distinct windings. The primary winding acts as the exciting coil and is wound for the full potential of the feeder and is connected directly across the feeder lines. The secondary winding carries the full-load current and is connected in series with the feeder, in the same manner as a series transformer. The operation of the regulator is shown diagrammatically in Figs. 1 and 2, in which a current of 100 amperes at 2 200 volts has its voltage raised and lowered ten percent respectively. Fig. 1 shows the regulator raising the feeder voltage to 2 420, while the current is reduced to 91 amperes. The remaining nine amperes flow from the generator through the primary winding of the regulator and back again to the generator. In Fig. 2 the regulator is lowering the feeder voltage to 1 980 and the remaining 11 amperes flow from the feeder through the primary winding of the regulator back again to the feeder. It will thus be seen that these regulators follow the same laws which govern transformers, and therefore if the voltage of the feeder is increased, the number of amperes in the feeder is decreased, so that the total energy in the circuit remains constant except for the small loss in the regulator.

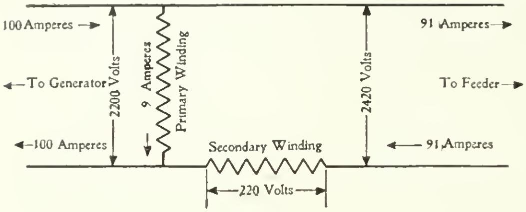


FIG. 1—DIAGRAM OF REGULATOR RAISING VOLTAGE TEN PERCENT

A regulator consists of a primary or energizing coil sending a magneitc flux through the secondary or series coil, which causes the voltage of the latter to change, depending upon the amount and direction of the magnetic flux passing through it. When the windings are at right angles, which is the neutral position of the regulator, the primary has no effect on the secondary winding and the voltage of the circuit is not affected by the regulator. By rotating

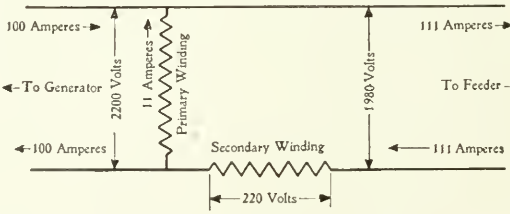


FIG. 2—DIAGRAM OF REGULATOR LOWERING VOLTAGE TEN PERCENT

the primary either way from the neutral position, a voltage is impressed on the series winding which either increases or decreases the feeder voltage. This action is analogous to that of a booster on a direct-current feeder. The primary and secondary consist of iron punchings wound for two poles. If the winding be distributed in an infinite number of slots, the resulting voltage will follow the sine curve. As the number of slots decreases, the voltage curve has an increasingly irregular shape, and for this reason these regulators are designed with a sufficient number of slots in both the primary and the secondary so that the voltage curve approximates a sine curve very closely.

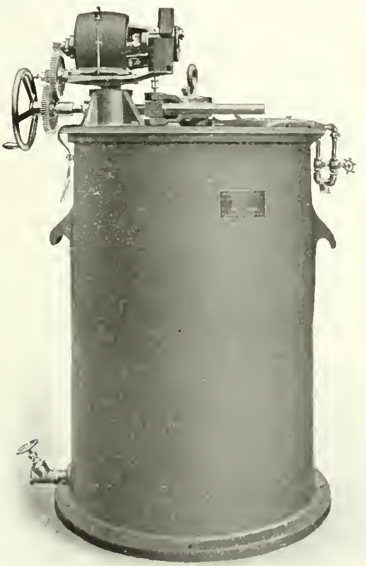


FIG. 3—POLYPHASE MOTOR-OPERATED INDUCTION REGULATOR

When the regulator is in its neutral position, the primary does not send any lines of force through the secondary and the latter, therefore, tends to create its own field and act as a choke coil. This condition is overcome by providing the primary with a short-circuited winding which is placed at right angles to the exciting winding. The short-circuited winding comes into play when the exciting winding approaches the neutral position, and it acts similarly to a short-circuited secondary of a transformer, so that practically no choking effect is evident in the secondary or series coils. If the short-circuited winding were not used the voltage necessary to force full-load current through the series winding would increase as the regulator is moved from the position of maximum boost or minimum drop, reaching a maximum when the regulator is in the neutral position. Since this voltage is at right angles to the working voltage, the result would be a poor power-factor in the feeder circuit. The short-circuited winding so cuts down this voltage of self-induction

that the voltage necessary to force full-load current through the secondary winding when the regulator is in the zero position is very little more than that necessary to overcome the ohmic resistance of the secondary coil.

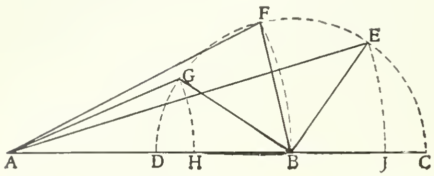


FIG. 4—DIAGRAM SHOWING OPERATION OF POLYPHASE REGULATOR

Polyphase Induction Regulators—The general appearance of one of these regulators is shown in Fig. 3. They differ from the single-phase regulator in that the induced voltage in the secondary winding has a constant value, and the regulation is effected by varying the phase relation between the line voltage and the regulator voltage. The primary winding consists of as many separate windings per pole as there are phases in the circuit, and these primary or shunt windings are connected to the corresponding phases of the circuit. These windings produce a magnetizing flux of practically constant value, which varies in position. The number of secondary windings on the stationary core also corresponds to the number of phases of the circuit and the voltage induced in them is of constant value, owing to the constant value of the magnetizing flux generated by the primary windings. The method of regulating line voltage is shown in the diagram, Fig. 4, in which the line *AB* represents the generator voltage of one phase of the feeder, and *BC* the voltage impressed on the regulator winding when the latter is in the position of maximum boost. In this positon, the generator voltage and the regulator voltage are in phase, and the resultant line voltage is represented by the line *AC*. If the regulator voltage is now displaced in phase through 180 degrees, the two voltages will be exactly op-

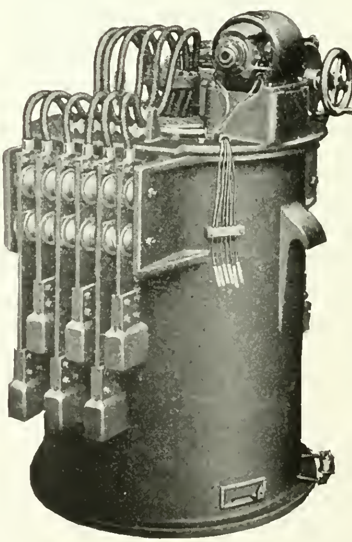


FIG. 5—SIX-PHASE MOTOR-OPERATED INDUCTION REGULATOR

posed in phase and the resultant feeder voltage will be represented by *AD*. When the regulator voltage is displaced in phase in the direction *BF*, the regulator is in the neutral position, as the resultant voltage *AF* is equal to the generator voltage *AB*. By rotating the primary from *BF* to *BE* the line voltage is raised by an amount represented by *BJ*, the resultant voltage being equal to *AE* or *AJ*. Rotating the primary in the opposite direction from the neutral position *BF* to *BG* reduces the voltage by an amount *BH*, the resultant line voltage being equal to *AG* or *AH*.

The essential parts of an induction regulator are a rotatable primary core with windings, assembled on a shaft and a stationary core with windings which is mounted in the regulator case. The rotor is operated by means of a worm wheel and worm, the shaft of the latter being driven either by a hand wheel or by a motor through spur gearing. The worm shaft of the automatic regulator is connected to the motor through a spur gear and pinion. A handle is also attached to the gear wheel so that in case of emergency the regulator may be operated manually, as shown in Fig. 5. Either alternating or direct-current motor drive is used, but the former is generally preferred, a brake being used in connection with the motor drive. This brake must be held in the release position when it is desired to operate by hand.

AUTOMATIC OPERATION—CONTROLLING RELAYS

The operating motors of automatic regulators may be controlled by means of relays. As the current-carrying capacity of the contacts or switches for starting, stopping and reversing such a motor must be ample and as the accuracy of regulation must be approximately from one-half to one percent, it has been found desirable to divide the control functions between two relays—first, the voltage regulating relay; second, the auxiliary relay.

The Voltage Regulating Relay is, in effect, a contact making voltmeter which is connected to the circuit to be regulated. Its functions are to close one contact when the voltage of the circuit is below the desired value, and to close another contact when the voltage exceeds this value. It has sufficient torque to make positive contacts with very slight changes in voltage and may be easily adjusted for any normal voltage, as well as for the permissible amount of change in voltage which causes the relay to act. This latter adjustment is very important because, on circuits with slowly varying

voltage, the contacts may be spaced much closer together than where the fluctuations vary widely and rapidly. A relay of this type is illustrated in Fig. 6, from which the method of operation may be readily understood. The upper stationary contact closes when the voltage is high, and the lower contact when the voltage is low. Screw adjustments on these contacts are used to vary the amount of change in voltage required to make contact, and a dash pot is used to damp out the minute vibrations of the contact pieces which would tend to make the relay too sensitive. A counterweight K is supported from a micrometer type adjusting piece. This adjustment is for the normal value of the voltage at which the circuit is to be held. The total energy required for a relay of this type is only ten watts at normal voltage, so it will not interfere with the ratio of transformation of a voltage transformer if the latter is required.

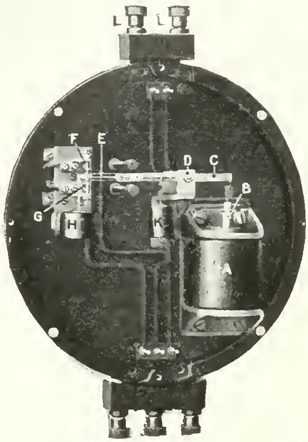


FIG. 6—INTERIOR VIEW OF VOLTAGE REGULATING RELAY

A—solenoid, *B*—spring supported core, *C*—balance beam, *D*—pivot bearings, *E*—moveable spring contact, *F*—upper stationary contact, *G*—lower stationary contact, *H*—dash pot, *K*—counterweight, *L*—binding posts for feeder circuit, binding posts for auxiliary circuit and relay at bottom.

A voltage regulating relay will also be found useful in cases where it is desired to regulate by hand as, aside from its function of controlling the automatic regulator, it can be used to light a signal lamp of one color when the voltage is too high, and one of another color when the voltage is too low, thus calling the attention of the station operator to the fact that the voltage should be adjusted.

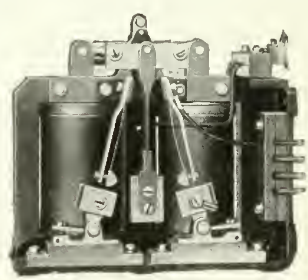


FIG. 7—AUXILIARY RELAY

The Secondary or Auxiliary Relay—This relay is connected between the voltage relay and the motor circuit and is designed to relieve the contacts of the primary relay from carrying the whole current required to operate the motor. The auxiliary relay is an elec-

trically operated double-pole double-throw switch with carbon contacts. The operation of this relay may be understood by reference to Fig. 7. It is so connected as to start the motor in either direction and at the same time release the motor brake.

The relative voltage variation of a circuit with and without the use of the potential regulator is shown by the curves in Figs. 8 and

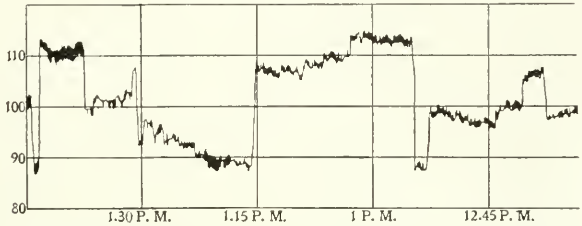


FIG. 8—CURVE TAKEN WITH A GRAPHIC RECORDING VOLTMETER ON THE UNREGULATED SIDE OF A FLUCTUATING CIRCUIT

9, which were taken simultaneously on the same feeder circuit, one set being taken on one side and the other set on the other side of the regulator.

By connecting the primary or voltage regulating relay to the circuit through a compensator, as shown in Fig. 10, the voltage may

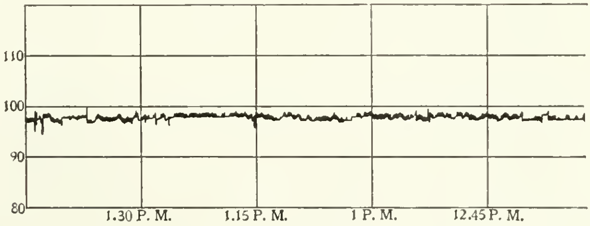


FIG. 9—CURVE TAKEN SIMULTANEOUSLY ON THE SAME CIRCUIT AS FIG. 8 AFTER PASSING THROUGH THE REGULATOR. VOLTAGE REGULATING RELAY SET FOR 98 VOLTS NORMAL, PLUS OR MINUS ONE-HALF VOLT

be regulated for a constant potential at any desired distant distributing point, such as a sub-station.

STEP-BY-STEP TYPE REGULATORS

The principle of operation of the step-by-step type potential regulator is practically the same as that of the induction regulator. Both consist of regulating transformers, but in the step-by-step type

the series coil is divided into a number of sections which are successively cut in or out of the circuit to be regulated, instead of varying the flux through the entire coil, as in the induction type.

The step-by-step potential regulator has been developed in two general mechanical forms, the drum type, and the dial type. The former comprises a drum and finger type switch, similar to a railway controller, and the latter a face plate with a dial switch for switchboard mounting.

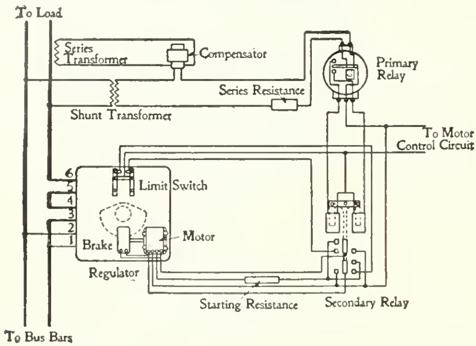


FIG. 10—DIAGRAM OF CONNECTIONS OF AUTOMATIC INDUCTION REGULATOR ON A FEEDER CIRCUIT

Drum Type Regulators—The drum and finger type regulators are of very substantial construction, as they contain no parts requiring delicate adjustment. See Fig. 11. A preventive resistance is used between the different contacts so that it is unnecessary to open the circuit when moving from one tap of the regulating transformer to the next tap. A spring-actuated, quick-moving central-stopping mechanism is provided so that it is impossible to burn out the preventive resistance, since this mechanism makes it impossible to leave the drum in any but the normal running position. This central-stopping mechanism also makes these regulators easy to arrange for distant control by means of chains or gears and shafts. Regulators of this type are all arranged to give as many as forty points of regulation. In many cases this large number of points is not absolutely necessary, but is desirable because the voltage per step is thus reduced to a small value and a corresponding increase in the life of the contacts results because of the reduced sparking at the lower voltage. This large number of points of regulation is obtained by the use of changing switches and floating coils. The floating coil is a part of the secondary winding of the regulating transformer which

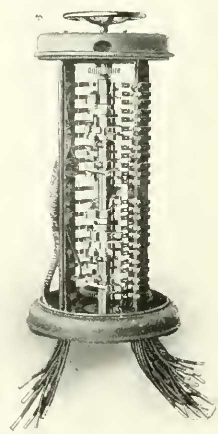


FIG. 11—DRUM TYPE STEP-BY-STEP REGULATOR WITH COVER REMOVED

is insulated from the main portion of the winding and is sub-divided by taps into a number of equal sections. The sub-divisions of the main secondary winding are much larger, each one being equivalent to the whole of the floating coil.

In the operation of the regulator, the floating coil and main winding are first connected in series with each other and with the line to be regulated. The floating coil is then cut out of the circuit step by step. When entirely cut out it is transferred to the next lower tap on the main winding, after which the floating coil winding is again cut out step by step and then transferred again. By continuing this process a large number of steps are provided with but very few actual taps on the transformer. Two of these floating coils are included in each regulator so that one can be transferred while the other is supplying the current to the line. All the points of regulation can be obtained by continuous motion of the handle, and there are no additional reversing levers of any kind to manipulate. The upper part of Fig. 12 shows the connections of the various coils for each different position of the regulator handle. The arrangement described applies to a regulator when used in connection with an independent regulating transformer. When regulators are used in connection with large power transformers, the regulating transformer can be omitted and auxiliary coils can be placed on the main transformer to provide the necessary taps for regulating purposes. The lower part of Fig. 12 shows the connections used when auxiliary coils are added to a large transformer. These connections are for a single-phase regulator. Where polyphase regulators are required, the connections consist practically of

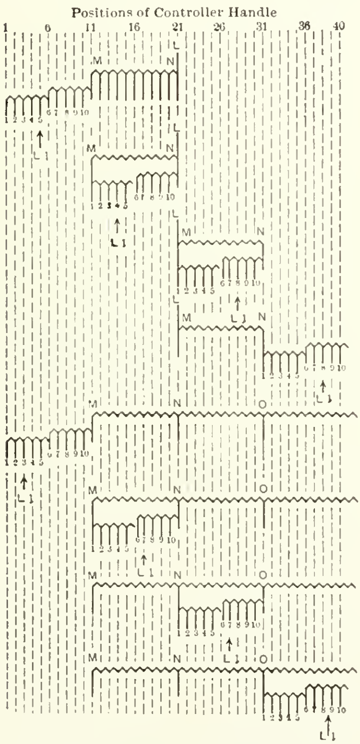


FIG. 12—DIAGRAM SHOWING POSITIONS OF FLOATING COIL ON DIFFERENT STEPS OF REGULATING TRANSFORMER

two sets of single-phase connections, and the controller is extended in length so as to contain double sets of drums and contacts.

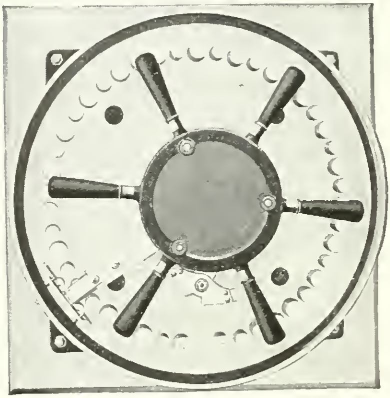


FIG. 13—DIAL OF STEP-BY-STEP POTENTIAL REGULATOR

Dial Type Regulators—Dial type regulators consist of a regulating transformer and a dial type switch. The regulating transformer is similar to the standard transformer except that the secondary winding is divided into several parts, giving a corresponding number of taps which are brought out from the secondary winding and connected to the various points of the dial. A dial of this type is shown in Fig. 13. It consists of a marble slab, upon which the contacts are mounted in a circle. The contact arm is arranged to move from contact to contact. It will be seen from the illustration that each alternate contact is of smaller size than the others. These small contacts are dummies and are used only as guides to prevent the contact arm from springing down between contacts when moving from one to the next. The panel also contains a changing switch, as shown in Fig. 14, which makes it possible to use the full range of the regulator for both raising and lowering the voltage. Since each contact on the dial is connected to a lead from the transformer, there is always a difference of potential between two adjacent contacts, and for this reason the contact arm must not touch the contact toward which it is moving until after it has left the contact upon which it was last resting. It is also undesirable to open the circuit each time in moving from one contact to the next. These conflicting requirements are met by the use of arcing tips which are placed on the contact

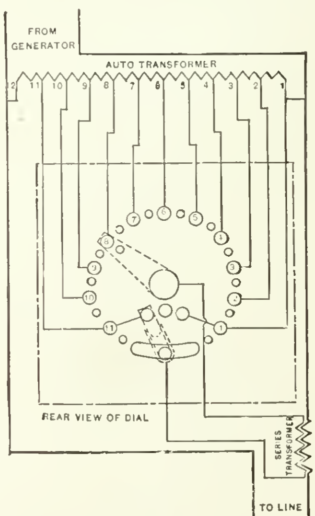


FIG. 14—DIAGRAM OF CONNECTIONS FOR 11 POINT DIAL, AUTO-TRANSFORMER AND SERIES TRANSFORMER

arm so that a very close adjustment can be obtained, and are so arranged that the contacts are not short-circuited, but always have a gap of from one-sixteenth to one-eighth inch in the circuit during the time of changing from one contact to the next. The column of air in this gap acts as a preventive resistance. Springs are connected to the handle so that a movement of the latter compresses the springs, and when they are released they carry the contact arm with them, thus making the change from one contact to the next in the least possible time.

UNIT SWITCH TYPE POTENTIAL REGULATORS

Special regulators of the unit switch type are used for handling heavy currents where step-by-step regulation is desired. Regulators of this type, as shown in Fig. 15, consist of a number of electrically-operated switches controlled from a master switch. These switches are arranged to perform practically the same cycle of operations as previously described for the drum type potential regulators. The transformer windings are divided into sections, and two floating coils are provided which are connected to various taps on the main auto-transformer. These floating coils have intermediate steps, and the successive operation of the switches connects the floating coils in proper sequence to the main auto-transformer, and transfers the line connection from one point of the floating coil to the next. The master switches are arranged with an automatic lock to prevent their being operated too rapidly, and the magnet switches themselves are so interlocked that the proper sequence of operation is insured. These switches may be either of the open type or entirely enclosed, the latter having their main contacts oil immersed.

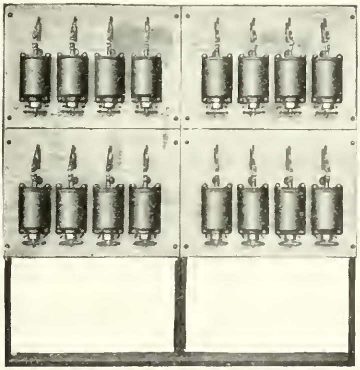


FIG. 15—UNIT SWITCH POTENTIAL REGULATOR

Regulators of this type are particularly well adapted for metallurgical purposes where the regulation is effected in the primary circuit and the secondary circuit is used for supplying power to the furnaces.

METER AND RELAY CONNECTIONS (Continued)

STANDARD RELAY CONNECTIONS

HAROLD W. BROWN

REVERSE CURRENT RELAYS

Electromagnet Type Reverse Current Relay for Direct-Current Circuits, with Inverse Time Element—This relay is very sensitive to small reverse currents. Only one shunt is required and this may also be used as an ammeter shunt. Fig. 14 is a diagram of connections. For e.m.f.s higher than 110 volts, an additional resistance is required in series with the field circuit.

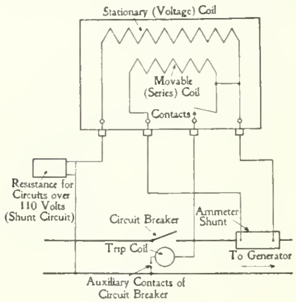


FIG. 14—CONNECTIONS FOR DIRECT-CURRENT ELECTROMAGNET TYPE REVERSE CURRENT RELAY WITH INVERSE TIME ELEMENT

Alternating-Current Overload and Reverse Current Relay—Polyphase circuits are protected either by a single polyphase relay for all the phases, or by one single-phase relay for each phase. Connections for the polyphase relay are as indicated in Fig. 15 for a two-phase circuit, and in Fig. 16 for three-phase. The tripping circuit connections are made to the lower middle, and upper left hand binding post (as viewed from the rear). The remaining three upper binding posts are for voltage connections and the lower four binding posts for current connections. For perfect operation, the current in the left hand current circuit must have the correct phase relation to the current in the left hand voltage circuit, and there must be a similar relation with respect to the currents in the right hand current and voltage circuits. If power is in the normal direction, and at 100 percent power-factor, the current in the current cir-

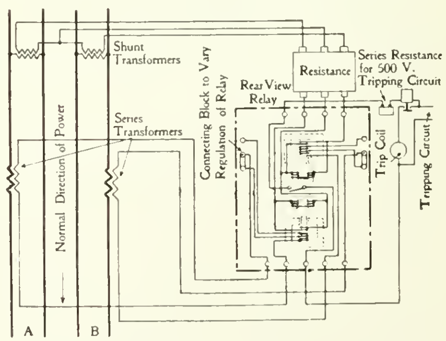


FIG. 15—CONNECTIONS FOR POLYPHASE OVERLOAD AND REVERSE CURRENT RELAY ON TWO-PHASE CIRCUIT

cuit must be in the same direction and in phase with the current in the corresponding voltage circuit. In the two-phase diagram, shown in Fig. 15, the voltage transformer of phase *A* is connected to the left hand voltage circuit of the relay (i. e., to the left and middle voltage terminals) and the current transformer of the same phase is connected to the left hand current circuit. Similarly, the voltage and current transformers of phase *B* are connected to the right hand circuits of the relay. At 100 percent power-factor, with power in the normal direction, the currents in corresponding current and voltage circuits are in the same direction and in phase.

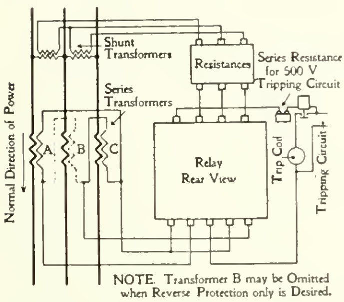


FIG. 16—CONNECTIONS FOR SAME RELAY AS IN FIG. 15 ON THREE-PHASE CIRCUIT WITH TRANSFORMERS DELTA-CONNECTED EXCEPT AS NOTED

In Fig. 16 the voltage transformer between lines *A* and *B* is connected to the left- and the one between *C* and *B* to the right-hand voltage circuit of the relay. The current transformers are delta-connected, and the lead from *A* and *B* is connected to the left- and the one from *C* and *B* to the right-hand current circuit. The lead from *A* and *C* is connected to both sides of the relay. The vector diagram, Fig. 17, shows that corresponding current and voltage circuits have the correct phase relation. Let the vectors *OA*, *OB* and *OC* represent the e.m.f.s between the three respective phases and the neutral. The e.m.f. between *A* and *B* is represented by the line *AB*. With the arrow pointing towards *A*, this line represents *A—B* or the e. m.f. tending to send current from *A* to *B*. Since *A* connects to the left hand, and *B* to the middle binding post, this vector represents the e.m.f. sending a current inward on the left. Now *OA*, *OB* and *OC* represents the e.m.f.s of *A*, *B* and *C* respectively measured from the neutral. Therefore their directions are correct to represent also the phase of the three currents flowing from the generator, if the currents are at 100 percent power-factor. One of the leads from the series transformers connects to the generator end of transformer *B* and to the opposite end of transformer *A*. The current in this lead, flowing toward the relay, is therefore *B—A*. This

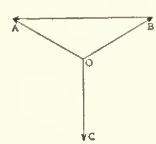


FIG. 17

flows in the left hand current circuit of the relay from the inner to the outer terminal. It is the same as a current *A—B* inward. In case of balanced currents, the phase of this combined current is represented by the vector *AB* in Fig. 17. The current in the current circuit is therefore in phase with the e.m.f. in the corresponding e.m.f. circuit. Similarly, the current in the other current circuit is in the same direction and in phase with the corresponding e.m.f. Thus the phase relations are such as are required by the relay for perfect operation.

It is possible to omit transformer *B* and still have approximately the same reverse current action; but the current is 30 degrees out of its correct phase, and is only 0.58 as strong as it would be otherwise; furthermore, there is no direct protection of phase *B*, if there is no transformer on that phase. Hence, transformer *B* should not be omitted where overload protection is required.

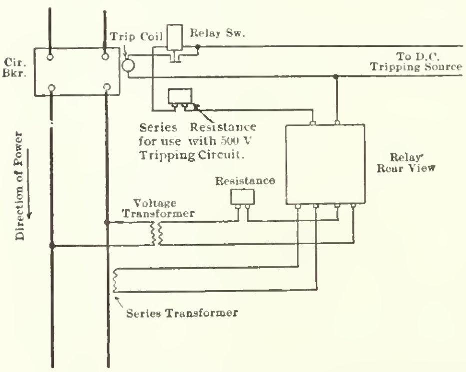


FIG. 18—CONNECTIONS FOR SINGLE-PHASE OVERLOAD AND REVERSE CURRENT RELAY ON SINGLE-PHASE CIRCUIT

See Fig. 20 for rear view of internal connections.

The Z-connection is not used with the polyphase reverse current relay, as with other polyphase relays, because the phase relations between the currents and e.m.f.s would be wrong with a Z-connection.

In the polyphase relay all the phases act on a single moving element, so that in case of overload or reverse current on one phase, if the currents in the other phases were in a normal direction and not too large, it would be possible to keep the relay from operating. The difficulty is overcome by using a separate single-phase relay for each phase, with the connections so arranged that if any one of the relays operates, it actuates the trip coil. For single-phase or two-phase circuits ordinary single-phase relays are used as shown in Figs. 18 and 19. The terminals at the top of the relay connect inside to the contact. The two lower left-hand terminals are for the current circuit, and the two lower right-hand ones for the voltage circuit. (The use of the relay switch as shown is referred to later.) In order to

secure the right phase relations between currents and e.m.f.s, with three-phase circuits, the e.m.f. circuits are Y-connected. The e.m.f. on each relay is then only 0.58 of the e.m.f of the transformers. Special low-voltage relays are therefore provided for use on three-phase circuits. Fig. 20 gives the three-phase connections and also the internal connections of the single-phase relay.

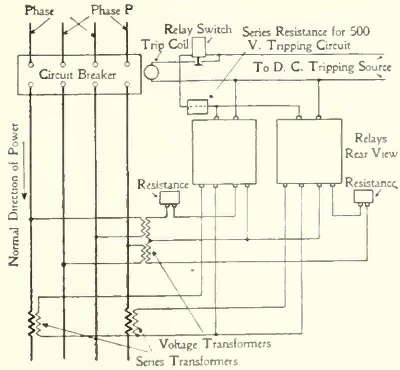


FIG. 19—CONNECTIONS FOR SAME RELAY AS IN FIG. 18 ON TWO-PHASE CIRCUIT

Three independent single-phase relays are sometimes mounted in a single case, with external connections as indicated in Fig. 21 for operation on a three-phase circuit. Their action is identical with that of three separate relays.

AUXILIARY RELAYS

It is sometimes undesirable or inconvenient to provide a single relay that will perform all the operations that are required in the protection of a circuit. In such a case an auxiliary relay is used, whose function is to perform the operations omitted by the main protective relay. The auxiliary relay is ordinarily connected to a direct-current circuit, and its operation is very simple.

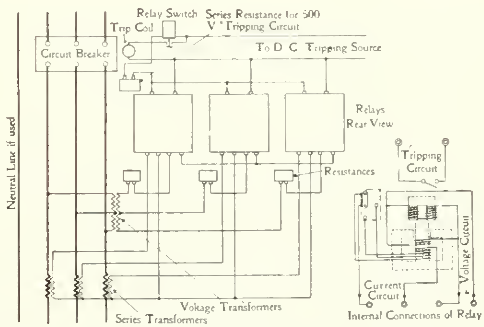


FIG. 20—CONNECTIONS FOR SINGLE-PHASE OVERLOAD AND REVERSE CURRENT RELAY ON THREE-PHASE CIRCUIT

This relay is the same as in Fig. 18, except that it is made for lower voltage, so that the e.m.f. circuits of the three relays may be Y-connected to the voltage transformers. Each line is protected by a separate relay. Only one trip coil is required.

Relay Switch—This simple auxiliary relay is actuated by a very small current. Its function is to close heavy contacts which in turn

carry larger currents that operate one or more circuit breakers. The connections are shown in Fig. 22. Relay switches are shown in connection with reverse current relays in Figs. 18, 19, 20 and 21. They may be similarly used in connection with any other relay.

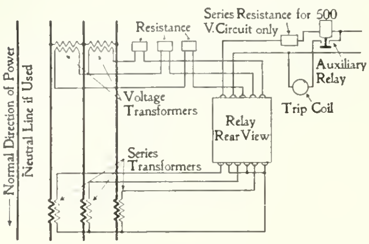


FIG. 21—CONNECTIONS FOR THREE-PHASE OVERLOAD AND REVERSE CURRENT RELAY CONSISTING OF THREE INDEPENDENT SINGLE-PHASE RELAYS AS IN FIG. 20 BUT MOUNTED IN A SINGLE CASE

Time Limit Relay—This relay begins to operate as soon as the contact is closed on the main relay. It takes a definite time for the contacts of the time limit relay to close, and this time element is introduced in tripping the circuit breaker. This time element may be varied by changing the setting of the relay. The main relay may be of any kind. Fig. 23 is a diagram of connections of this relay used with an overload instantaneous relay. The terminals of the winding are brought out to the upper binding posts. Each of the lower terminals connects to a contact; when these contacts are closed they connect inside to the upper left hand terminal (as seen from the rear).

IN GENERAL

A part or all of the following circuits are required by relays in the performance of their functions:—

Current circuits on one or more phases.

Voltage circuits on one or more phases.

Tripping circuit of main relay.

Tripping circuit of auxiliary relay.

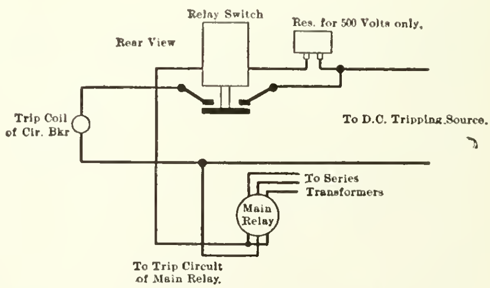


FIG. 22—CONNECTIONS FOR AUXILIARY RELAY SWITCH USED IN CONNECTION WITH MAIN RELAY

The current circuit on a single-phase system may be connected to a transformer on either side of the line, if neither side is grounded. The only precaution to be observed is that where there is a voltage circuit in the relay, the current in it must be in the same

direction as that in the current circuit.* On a two-phase system care must be observed that currents in corresponding current and voltage circuits are connected to the same phase, and flow in the same direction. If the relay has no voltage connections, the only precaution necessary is that there be one transformer on each phase. Three-phase Z-connections must be made with due attention to phase relations and direction of current, even though there be no voltage connections. The current circuit of a direct-current relay may be on either side of the line, if neither side is grounded. If there is a voltage circuit, the current in it and in the current circuit must be in the same direction. If the relay is polarized, the direction of current must be in accordance with the polarization.

The tripping circuit is usually direct-current, but not necessarily so. The nature of the tripping circuit is determined chiefly by the trip coil, rather than by the relay. If the volt-amperes required by the trip coil are too great for the relay contacts, an auxiliary relay is used. The contacts of both the main and the auxiliary relay are ordinarily connected to the same direct-current source of power. It is immaterial which terminal connects to the positive side of the line, but care must be observed where a main and an auxiliary relay are connected to the same line that the circuit of each is complete, from one side of the line to the other.

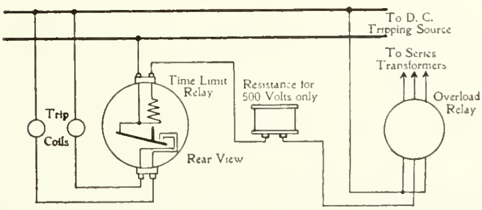


FIG. 23—CONNECTIONS FOR AUXILIARY TIME LIMIT RELAY USED IN CONNECTION WITH AN OVERLOAD INSTANTANEOUS RELAY

The advantage of series tripping lies chiefly in not requiring an extra tripping circuit. The chief disadvantages are that the power required for operating the trip coils is rather heavy for series transformers, and that circuit breakers as at present designed are not so well adapted to series as to shunt tripping. Shunt tripping is therefore usually to be recommended where conditions permit.

*For convenient assumptions regarding direction of current refer to the first part of this article appearing in the JOURNAL for May, 1908.

THE CARE AND MAINTENANCE OF STORAGE BATTERIES

F. A. WARFIELD

STORAGE batteries are installed with certain definite results in view and in order that these results may be realized and the best service obtained, a clear understanding of their action and diseases is necessary. Unlike engines, generators and other apparatus usually found in a large station, storage batteries, when abused, give no visible sign that they are not working properly, but continue delivering current until severely injured. If the operator in charge of the batteries will always remember that his apparatus will do so much in a given time and no more; that they must be used and treated as carefully as an engine and generator; that any attempt to make them do more than the company who furnished them guaranteed, will only involve failure, dissatisfaction and expense, he will have mastered the substance of the best set of instructions.

CHARGING

Batteries should ordinarily be charged at the normal, or eight-hour rate, which in all cases is specified in the contract under which the batteries are sold. The voltage required to start the charge is about 2.15 volts per cell. If this voltage does not give the required ammeter reading, adjustments should be made by means of rheostats installed for the purpose. When charging a fully discharged battery, the writer has usually obtained best results by using a variable rate of charge, and the following method is suggested: Start charging at fifteen percent above the normal rate, maintaining this rate until the voltage reaches approximately 2.5 volts per cell. At this point the current should be reduced to the normal rate and the charge continued until the voltage stops rising.

The general behavior of a battery on charge is as follows:—When the charging current is first applied the voltage of the battery rises immediately to about 2.15 volts per cell. During the first hour of the charge the voltage rises rapidly until it reaches about 2.25 volts per cell. As the charge progresses, a very gradual rise is observed, until at about 2.45 volts per cell a sudden jump is taken to nearly the maximum value, at which point the voltage remains practically constant, with both positive and negative plates giving off

gas freely while the solution is perfectly clear. The evolution of gas usually begins at about 2.3 volts per cell, the bubbles gradually increasing in size as the cell becomes fully charged. Under ordinary operating conditions a battery may be considered fully charged when the voltage reaches a constant value, but at least once a week this method of determining the state of charge should not be relied on.

There are three ways of determining when a battery is fully charged:

1—By the voltage reaching a constant value.

2—By the color of the battery plates.

3—By the specific gravity reaching a maximum constant value.

It is very important that the battery be fully charged, but it is just as important that it be not overcharged. In the same way that the voltage reaches a maximum constant value, so will the specific gravity of the electrolyte and readings of the individual cells of the battery in use should always be taken at least once a week with a hydrometer. These readings will act as a check on the voltage and, while it is not necessary to take them every time the battery is charged, it is very important that it be done frequently.

The time required for the charge is, of course, variable and will depend upon the condition of the battery when the charge is started. In general, it may be assumed that about twenty percent more charge is required than discharge obtained. At least once in every two weeks the battery should be given an overcharge. To do this, charge the battery at the normal rate until the voltage reaches a [illegible] value. At this point drop the charging current [illegible] the normal rate and continue to charge for three or four hours. While doing this it will be noticed that the specific gravity of the electrolyte will continue to rise for an hour, or even longer, after the voltage has become practically steady. This overcharge should be continued until the specific gravity becomes stationary.

If, in case of an emergency, it becomes necessary to charge more quickly than usual, the charge may be started at about twice the normal rate and continued until the battery commences to gas and the voltage reaches 2.6 volts per cell. At this point the electrolyte will have a milky appearance and the battery will be gassing very freely. The charge should then be lowered to about 1.5 times the normal rate and the charge continued until the voltage again rises to 2.6 volts per cell, when the charging current should again be lowered. This proportionate reduction should be made every time the voltage reaches 2.6 per cell until the normal rate is reached,

when the charge can be continued to the end in the usual manner. Great care must be taken not to overcharge excessively at a high rate, as this causes rapid shedding of the active material. At least once a week is often enough for an overcharge, provided the battery is in constant use. If the battery is only used spasmodically, or is kept floating on the line for an emergency, it is a good plan to discharge the battery at least once every two weeks, and then overcharge.

TEMPERATURE

The temperature of the battery must never be allowed to exceed 100 degrees F., the cells near the middle of the battery being used as a guide. If the temperature is found to be rising too close to the limit, the charge should be lowered or stopped. Experience has shown that the best results, both when charging and discharging, are obtained when the temperature is between 70 and 90 degrees F. A considerably lower temperature will materially reduce the available capacity, this reduction being regained with the return to normal temperature. If the battery gives its full rated capacity at 70 degrees F., at 30 degrees it will give about 76 percent of its capacity, while at 90 degrees it will give about 112 percent. Low temperature never injures a battery but, on the contrary, if the temperature be maintained for any length of time above normal, the wear on the plates is excessive.

ELECTROLYTE

The level of the surface of the electrolyte should be at least one inch above the top of the plates in the cell. When fully charged, the specific gravity of the acid in the majority of the lead batteries is from 1,200 to 1,225. Whenever a battery is given an overcharge, the specific gravity should be tested and adjusted. In making this adjustment, it should always be remembered that it is to be done towards the end of the charge and while the charging current is on. Should the specific gravity in some of the cells be lower than the majority, it is a better plan to charge these cells separately by cutting them clear from the battery and charging them separately at a low rate. When the cells are large and connected up permanently in series and it becomes necessary to charge a single cell to bring it up to condition, two wires may be run to the terminals of this cell from a separate source of current and the cell charged independently. If the gravity of a cell increases, it is a sign that this particular cell has, for some reason or other, been run down lower than its fellows and needs additional charging. If, however, the gravity does

not come up and the temperature does not increase with charge, extra acid should be added. It is seldom necessary to add acid to a cell to bring up gravity (that is, gravity 30 or 40 degrees below normal). Never add acid until the cause of lowness is determined. With a battery in normal condition, the acid will usually be found to be high in gravity and water should be added to make up for the electrolyte lost by evaporation and gassing. This water should always be introduced into the cell at the bottom by a hose, or lead pipe, as the water will, if poured in, float on top and mix very slowly, since water is lighter than the acid.

TROUBLES AND REMEDIES

The principal causes of trouble in a battery are:—

1—Loss of capacity.
2—Fracture and buckling.
3—Sulphation of plates.
4—Reversal of cells.
5—Impurities in electrolyte.

Loss of Capacity—Internal short-circuits are indicated by the failure of the voltage to come up on charge, with little or no ebullition of gas at the end of the charge, together with a solution of muddy color and a temperature above normal. This is usually due to a bridging of the active material between the adjacent plates or a filling of the bottom of the jar with sediment sufficient to reach the bottom of the plates. The bridging between the plates can be removed by passing a strip of glass or wood between the plates. It is usually much more difficult to remove the sediment from the cells, but the following method is advocated:—Charge the battery completely at a low rate and when fully charged, separate the cells. The elements should then be removed and cleansed with water, using a hose to sprinkle and remove the particles of sediment. Pour the acid from the jar in a careful manner so as not to stir up the sediment as the acid can be used again. In case it is not possible, due to the size, to remove the element from the jar or tank, the sediment may be removed by stirring it up and pumping it out, using for the purpose an acid-proof pump. After as much sediment as possible has been removed, draw off the acid and flush the jar or tank with pure water (using rubber hose) until it is thoroughly clean, then refill with acid. If the acid does not cover the plates, add new acid of the gravity recommended by the makers of the battery. After this has been done, charge for about 12 hours at the normal rate until the voltage is at a maximum

and the battery gassing freely, then discharge to see if the voltage of the cells are all even. As the discharge progresses, the voltage of the battery, as a whole, should be read at 15-minute intervals, and when it reaches about 1.85 volts per cell, the voltage of each cell should be taken separately and the cells whose voltages are lower than 1.8 should be marked. This discharge should be followed by a charge until all cells are up to voltage, when the low ones should be charged separately until all are approximately even.

Insufficient Charge—This trouble is usually encountered with small batteries where incandescent lamps are used in connection with the switchboard to give the charging load. These lamps become old and partially burned out and fail to give sufficient charging current, the result being that the battery does not give its rated capacity. When this occurs and no other trouble is present, the battery should be placed on charge with new lamps and watched to see that it gasses freely and that the voltage reaches at least 2.65 per cell. Cases have come under the writer's notice where large batteries have suffered from this cause and in nearly every case the trouble has been traced to the fact that the operator relied entirely for his charging on a voltmeter which was reading incorrectly. If the battery is occasionally charged until the specific gravity of the electrolyte ceases to rise and the voltmeter reading noted, this trouble will be avoided.

Reversal of Charging Circuit—It sometimes happens that the polarity of the charging circuit becomes reversed. This trouble seldom occurs in large installations. Unless detected and remedied before the battery is put on charge, considerable damage may be done. If this happens, see that the terminals of the charging circuit are polarized properly; then charge the battery at the normal rate until the voltage and specific gravity of the electrolyte are both at a maximum. This may take from 12 to 96 hours, depending upon the condition of the battery when the trouble was discovered.

Fracture and Buckling—Fracture and buckling are due to the discharge being carried too far, the rate of discharge being too rapid, or the plates being improperly made. The remedy for the first two reasons given above is obvious. For a defective plate there is no remedy. Shedding of the active material usually accompanies the foregoing and is usually greatest when the battery is overcharged too far or discharged too rapidly or too low. When this shedding takes place in a greater degree than ordinary, the remedy is to

charge at lower rates, seldom charge above 2.5 volts per cell. Never discharge below 1.8 volts per cell.

Sulphation of Plates—This is usually evidenced by the plates assuming a whitish appearance, accompanied by a low acid gravity when no bridging or short-circuiting of the plates can be detected. The chief cause of sulphation is over-discharge. A rapid discharge either of a part or of the whole mass of active material will also cause the same trouble. Excessive discharge rates also tend to form a surface layer of sulphate, which prevents the inner portions of the active material from participating in the discharge. This forces a small portion of the plates to do the whole work, thus causing an over-discharge of the working part.

The best treatment for sulphated cells is a matter of opinion, but by charging at a low rate (about one-half of the normal eight-hour rate), for from 40 to 90 hours the sulphate is gradually reduced. Several cycles of charge and discharge are usually necessary to bring the battery up to its full capacity. If only one or two cells are low, a quick method is to reverse the low cells on discharge so that the discharging current passes through the cells as charging current. This will lower the battery volts as a whole twice the voltage of each cell reversed and is only recommended when the battery is small and the e.m.f. of the battery ample for its work. Carefui watch should be kept for sulphating and if the plates begin to turn lighter than normal, the trouble should be located and removed by giving the sulphated cells a good over-charge. If avoidable, never let the battery or a section of it stand idle for any length of time when discharged, as this is one of the most frequent causes of sulphation.

Reversal of Cells—This occurs only when the discharge is carried down to a dangerous point and seldom happens except in cases where a cell loses its capacity through some accident or defect, and its discharge is ended before the other cells in the battery with it have been completely discharged. The remedy is to re-charge and continue the charge until the cell is fully up to normal condition. First, however, the capacity loss should be ascertained or the cell will again reverse on discharge.

Impurities in the Electrolyte—These are shown by disintegration of the plates, low voltage and decreased capacity. They are usually due to the presence of iron or chlorine. The acid can be tested for iron by adding several drops of nitric acid to a test tube one-quarter full of acid, then filling the tube with strong ammonia

water. The acid can be tested for chlorine by adding distilled water to a tube one-quarter full of acid. Enough water should be added to fill the tube. To this should be added a few drops of weak nitrate of silver solution. A white curdy sediment, turning blue in the sunlight will indicate that chlorine is present. Nothing but a cleaning of the cell or battery will remedy this trouble. To do this the elements should be thoroughly cleansed and left in running water for two or three days. Then re-assemble and charge as usual.

TO PUT A BATTERY OUT OF COMMISSION

If the battery is to be put out of commission for two or three months, it should not be allowed to stand in the electrolyte unless a small charge and discharge can be given at least once a week. It should be slowly charged until full, then discharged at the normal rate for two hours. After this the electrolyte should be drawn off and pure water immediately put in the tanks. Continue the discharge at about one-half the normal rate until the voltage reaches about 0.5 of a volt. To do this it will probably be necessary to short-circuit the individual cells. The plates should then be washed thoroughly by using a hose on each element, then soaked in running water for 24 hours and allowed to dry. When put in commission again, pour in the electrolyte and give a long over-charge.

SUMMARY

In conclusion, the following rules should be observed:

1—Never discharge a battery below 1.75 volts.

2—Never adjust the specific gravity of solution by adding acid until cause of the change in gravity is found and remedied.

3—Never allow the acid to get below the standard level, that is, one inch above the top of the plates, otherwise the plates may become exposed and sulphate rapidly.

4—Always maintain the acid at the specific gravity specified by the maker of the battery by testing and adjusting at least once in two weeks.

5—Never let the battery stand in a discharged condition. It should be immediately re-charged.

6—At frequent and regular intervals give the battery a good over-charge at a low rate.

7—Keep the battery and all connections clean.

8—Keep all electrical connections tight.

9—Remedy all trouble immediately.

10—Use only pure water and pure acid for the electrolyte.

EXPERIENCE ON THE ROAD

R. F. HOWARD
Canadian Westinghouse Company, Ltd.

EASE WITH WHICH A TURBO-GENERATOR WAS PARALLELED

CIRCUMSTANCES made it necessary for a certain hydro-electric power company to get a 1 500 kilowatt steam turbine unit into service sooner than had been originally contemplated. The turbine and generator were already installed but the switchboard had not yet been received. A temporary switchboard was erected on which were mounted a polyphase wattmeter, two generator ammeters and pilot lamps. The generator leads were brought to the switchboard and from it the lines were extended to the main operating station about half a mile away. Here the lines were connected to an oil switch which was used to connect the turbo-generator in parallel with the rest of the system. A synchroscope was installed at the main station and the steam station was advised by telephone as to the relative speeds and phase relations of the two plants. After the connections were completed the stations were operated in parallel daily during the peak hours for over a month. But for the fact that the meters on the temporary board showed signs of life no one in the steam station could tell when the connection between the stations was made, so smoothly was the system paralleled. Only a trifling adjustment of the steam turbine governor was necessary on the first occasion, and practically no adjusting had to be done on subsequent occasions.

No voltmeters were used on the exciter or alternator circuits, indications of the potential being obtained from pilot lamps. Not the slightest mishap occurred while the temporary outfit guided the men in the operation of the plant. This method of paralleling might seem at first thought to be hazardous, but no great trouble should be experienced if the proper indicating devices are used and care is taken by the operator in connecting the machines together.

PARALLELING GENERATORS OUT OF PHASE

A large manufacturing company operated two water power plants in multiple, one situated in their mill and the other about ten miles away. The generator in the mill was a 500 kw, three-

phase, 2 500 volt machine and was connected in parallel with the rest of the system twice every twelve hours.

The writer was installing a steam turbine set which was to operate in multiple with the other systems and, as the results obtained when paralleling the turbo-generator were so satisfactory, attention was called to the unit in the mill where heavy cross-currents were experienced each time it was paralleled with the rest of the system. In looking over the connections it was found that the synchronizer was connected to phase *1* and *3* on the generator side of the switches and to phase *1* and *2* on the other side, so that each time the attempt was made to synchronize the generator phase *1-3* of the generator was brought into step with phase *1-2* of the line, whereas corresponding phases of the generator and line were connected when the switches were closed, thus causing the heavy cross-currents. The synchronizing connections were changed and no further trouble was experienced in paralleling. The units had been paralleled in this way for nearly three years.

PHANTOM GROUNDS

A municipality installed a plant for street and house lighting, all the feeders being lead sheathed and underground. On starting up the plant the ground detector indicated grounds on the system. Much time and money was spent in trying to locate the faults. The ground detector consisted of a voltmeter of the switchboard type operated from the low tension side of a 15 watt potential transformer, 2 000 to 100 volts, and so arranged that one terminal of the transformer could be connected to each phase of the generator and the other terminal connected to ground. When used in this way the voltmeter always gave some indication.

However, no grounds really existed on the system, the indications being due to condenser effect, for with the ground detector connections as stated, there was sufficient charging current in the transformer winding and voltmeter to make the instrument read and give the operator a false indication.

Another case similar to the above was investigated recently where an alternator was reported "grounded." The alternator was connected to a bank of transformers and it was known that a ground existed on the system, which was afterwards found in

one of the transformers. The observer had taken readings on a voltmeter from the three terminals of the machine to ground, and concluded that this was sufficient proof of the generator being grounded. The reason that the voltmeter read in this way was that the armature winding of the alternator had considerable capacity to ground, and a circuit was made through the voltmeter when connected as described.

Very different results were obtained by using transformers of various capacities to operate the voltmeter; the highest reading was obtained when using a voltmeter transformer, but with a five kw transformer there was no deflection. The indications on the voltmeter would depend upon the impressed voltage on the high tension side of the transformer. The different voltmeter readings with the different transformers are accounted for by the fact that the magnetizing and iron loss currents varied considerably in the different sizes used. The smaller the transformer the higher the voltmeter reading. The five kw transformer required a magnetizing current that would cause most of the drop to be across the condenser effect.

TRANSFORMER TROUBLES

A ground was observed on a high voltage system being fed by ten oil insulated, water cooled transformers. Considerable time was spent in locating the trouble and it was finally traced to one of the transformers. Investigation showed the trouble to be due to water in the oil that seemed to concentrate itself at one spot on the insulation and iron. Condensation had taken place on the cooling coils just inside the case and where the lagging had been torn off. The drops of water fell into the oil and went to the bottom of the tank causing the trouble. New lagging put on the coils effected a cure, the transformer continuing in operation without further difficulty.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

115—Field Discharge Resistance—What is the approximate correct ratio between the ohmic resistance of a field discharge resistance and the field with which it is to be used? H. W. A.

The amount of ohmic resistance used in a field discharge resistance is an arbitrary amount varying anywhere from that of the field with which it is to be used, to several times that amount. The field discharge switch is so arranged that the discharge resistance is connected across the line before the field circuit is actually broken. The energy of discharge to be dissipated when the field is opened, is very small compared with the energy drawn from the line by the discharge resistance while the field is being cut off from the source of supply. The discharge resistance is, therefore, designed with sufficient capacity to carry the current due to full line voltage while the switch is being opened, without undue heating.

H. C. N.

116—Insulation at the Ends of Induction Motor Coils—Please explain how the ends of the coils of induction motors are taped after the coil is inserted in the slots. The ends are bent up for convenience in taping, but on turning them back to place the tape goes with the coil, leaving the upper side of the coil close to the slots exposed for about one inch. I would like to know how this may be avoided.

A. E. S.

Overlay the turns of the tape 75 per cent or more of its width on the coil where it leaves the slot. This allows for material to cover the coil after it is bent. Hold the first turn of the tape in position while bending the coil down to position. R. A. MC.

117—How are the magnetic switches on the tracks of the Pittsburg Railways Company operated? I know what the motormen do to go from one street to another but do not understand how the apparatus works.

W. R. C.

The general method of operation of these switches can be seen by referring to Fig. 117(a). As may be inferred from the connections, to go on the straight track the motorman

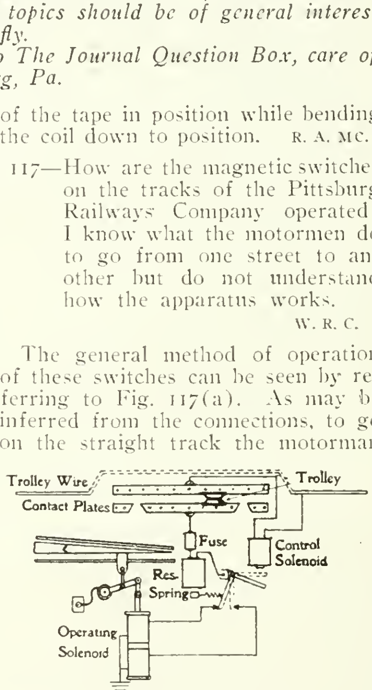


FIG. 117 (a)

allows the trolley on his car to coast under the switching device. To set the switch for the curve the motorman keeps current on while the trolley wheel passes under the switching device. The Pittsburg Railways Company reports that these devices work successfully. Some of them are located at switches where as many as 1,000 cars pass per day. The switch operating solenoid requires only about 2.5 amperes and hence the resistance is used in series. A spring is attached to the contact maker which can be adjusted so that the currents due to the lights and heaters will not cause the solenoid to operate the contact maker.

118—What causes sparking between the brush and the brushholder of a direct-current machine and how can it be remedied?
H. E. B.

Sparking between the brush and brushholder usually occurs as a result of bad contact between the carbon and the metallic parts, which are provided to carry the current from the carbon to the main brush leads. This can be remedied by making a good contact between the carbon and the flexible copper lead which is usually supplied to carry the main part of the current from the carbon to the brushholder from which it is conducted to the brushholder rod and from there to the main terminal.
L. T.

119—Motor-Generator Insulation Testing Set—Please specify the characteristics required of each unit of a motor-generator testing set used for testing insulation where constant voltage and small current are required, the motor to be operated from a 220-volt direct-current supply and the voltage of the high tension end to be 100 000 volts.
W. H. K.

The subject of insulation testing is treated in an article by Mr. C. E. Skinner, appearing in the Journal for September '05, p. 538 and continued in the succeeding October number, p. 612. An explanation of many of the principles involved is given therein. The kind of testing service for which the set is to be used is one of the factors determining the capacity of the apparatus. It is not usuallly found convenient to wind a transformer for 100 000-volt secondary potential of a smaller capacity than 25 kw. With a transformer of this capacity, it would ordinarily be advisable to have a motor-generator set of equal capacity because the testing set would then be available for any test requiring a capacity of transformer within this range, whereas if a motor-generator set were supplied for service requiring 100 000 volts, but only small current, the testing set would be limited to this service alone.
C. E. S.

120—Operation of Railway Motor Equipment—We have a 35-ton car equipped with four 75-hp motors. Motors 1 & 2, and 3 & 4 are connected in series. Is trouble liable to result to the equipment if No. 2 armature is removed without cutting out No. 1 motor (running the car with three motors)? Is trouble more likely to occur on fast limited cars with few stops, or on local service with many stops, if the car is operated properly?
C. B. F.

The effeect of this arrangement would be to overload the second motor of the set in which one was cut out and at the same time operate the first set of motors (1 & 3) at less than their normal capacity, due to the fact that with approximately equal counter e.m.f. maintained in all three motors the total drop would be increased as the drop across the single motor of the second set would be greater than across the other two in parallel. This would limit the current, but not sufficiently to prevent an overloading of the single motor. It would not be objectitonable, however, as an emergency arrangement. The ordinary arrangement would be to cut out both motors of the second set and operate the first two motors in parallel. The only advantage of the arrangement which you suggest would be in the possible increase in the total adhesion due to the third motor being maintained in service. If it were found possible to make the change of connections conveniently, a suggested improvement would be to operate the three motors in parallel. This would, of course, require that the resistance grids have sufficient capacity and resistance. It will be apparent that with a greater number of accelerations on local service than on suburban service the former would be the more severe condition to contend with, with the equipment in a crippled state.

121—Care of Commutators—Should commutators be run dry or lubricated, and if the latter, what is the best lubri-

cant and how often should it be applied? If run dry, will occasional cleaning be necessary and if so, what compound is best for this purpose? Do the location of the motor or the conditions of service determine this question? For example, a 10-hp motor is used to operate a coal elevator. Coal dust persists in collecting on the commutator which we have always run well lubricated. The wear has been so excessive, however, that the commutator has had to be turned down several times. It seemed probable that the dust and grit collecting on the commutator caused it to wear faster than if it were run dry. What is the solution of this and similar problems? H. E. B.

Commutators should be lubricated sufficiently to prevent chattering of the brushes. A small amount of clean engine or generator oil applied with a clean cloth is a satisfactory lubricant. It will also keep the commutator clean if applied with sufficient frequency, the number of applications desirable depending on local conditions. To prevent the oil from injuring the insulation of the commutator, it should be wiped off with a clean cloth as soon as applied. Possibly the 10-hp motor you mention is receiving too much lubrication which may cause the coal dust to accumulate and thus cause rapid wear of the commutator. If brushes containing a considerable percentage of graphite are used lubrication will be unnecessary. However, if oil is applied as mentioned above for the purpose of cleaning the commutator and immediately wiped off the results will usually be satisfactory. This should be done as often as the commutator gets dirty. G. W. C.

122—To Dry Out The Stator Winding of a three-phase, 60-cycle, 50-hp, 400-volt induction motor, what method should I follow? I have available standard alternating-current voltages from 110 volts to 33 000 volts H. C. K.

Take out the secondary or rotor and connect the primary winding across the 110-volt circuit which you state that you have available, connecting sufficient resistance in series so that not more than one-half of full-load current will flow in the winding. Keep this on about 48 hours. If the motor does not warm up the current may be increased until the temperature is about 150 degrees F. After 48 hours, test the motor winding for grounds and, if there are none present and the motor seems dry, replace the secondary and run the motor on light load for 12 hours. After this the machine should be in satisfactory shape to put in service. A. M. D.

123—Skewing of Rotor Slots in an Induction Motor—In induction motors — single or polyphase—what effect has the skewing of the rotor slots on the starting torque and the slip? G. D. L. R.

With straight slots there is a variation of the starting torque depending on the relative position of the rotor and stator slots. Skewing the slots of the rotor tends to equalize the high and low torque points at starting. The skewing has practically no effect on the slip, although there is a slight theoretical change. G. H. G.

124—Wattmeter Connections — If the disc of a polyphase integrating wattmeter revolves in the proper direction, is this conclusive proof that all the connections are correct, i. e., could it revolve in the proper direction and not register correctly the energy flowing in the three-phase circuit? F. C.

The fact that a polyphase integrating meter revolves in the proper direction is no indication that the connectitons are correct. In fact, with a very low power-factor one of the phases of the meter tends to run the meter backward. If this phase were reversed the meter would run forward even faster than with correct connections. H. W. B.

125—Choice of Distributing Systems—In case it is desired to supply electric current for a number of factory and office buildings as described in the following, what system of dis-

tribution and transmission is best adapted and most economical; direct-current three-wire or alternating-current and if alternating-current, single, two or three-phase, and why? A central power station of about 10 000 hp is located not more than 1 200 to 1 500 feet from the farthest factory to supply current for light, elevators and such manufacturing as desired. There are 21 buildings in all, eight stories high, each covering about 20 000 square feet. The generators will be driven by the latest improved producer gas engines. J. L. L.

A three-wire, 110-220 volt direct-current system, using 110 volts for lighting and 220 volts for power would be most suitable to these conditions. Alternating-current, two or three-phase distribution would be preferable were the distance of transmission great, or were it desirable to use induction motors in the manufacturing plant because of the nature of the work being such as to cause commutation trouble in the direct-current motors—a case which often occurs in plants where the air is filled with dust. Direct current has the advantage of being more satisfactory for lighting and, possibly, for power as far as elevators and cranes are concerned, as it may be found that more satisfactory controlling apparatus can be obtained for motor applications of this kind. If the 10 000 hp plant referred to is intended to supply power for other purposes than the factory and office buildings mentioned, it might be advisible to install a high tension polyphase plant, and at the factory install a motor-generator set or rotary converter for the purpose of obtaining direct current for the elevators and cranes, an arrangement which is often used in practice. W. I. B.

126—Power-Factor—A 250 kw, three-phase, 3 300 volt, 500 r.p.m. alternator is connected through three transformers to an approximately balanced incandescent lamp load at the end of a transmission line about one and one-half miles long. When the machine is running at one-half or any other load can the power-factor of the alternator be changed by varying the field excitation, load and voltage remaining constant? What effect does variation in these two latter quantities have on the power-factor of the circuit? If two alternators were running in parallel on this circuit, how would a variation in the field excitation of either one effect the power-factor of each one? F. H. C.

Power-factor is a function entirely of the character of the load upon an alternating-current system, and not at all of the generator from which the power is derived. It follows, therefore, that no changes which are made in the generators of an alternating-current system can have any effect upon the power-factor of the load which they are driving, except as the changes in the generators change the character of the load. For instance, a change in the voltage or the frequency of the generators would change, to some degree, the power-factor of the load taken by induction motors, etc. In the case cited in the first part of the above question, therefore, changing the field excitation of the generator would change the voltage upon the load. The conditions mentioned, namely, keeping the voltage and load constant and varying the field excitation of the generator is an impossible one. If a number of generators are operating in parallel upon a given load the power-factor of the various units which are operating would be changed by varying their excitation. Such a change, however, has no effect whatever upon the power-factor of the load but only upon the power-factor of the individual generators supplying the load. Assuming that a load of 70 percent power-factor is being operated from two generators; with proper adjustment of the fields of these generators the load taken from each of the two generators will show a power-factor of 70 percent. If, now, the field of one of these generators be

increased and the other decreased the power-factor of the load taken by the generator with increased field will become lower and that taken by the generator with decreased field, higher. The power-factor of the load itself, however, remains constant. With the changes indicated above, the generator which is receiving an increased field current will deliver more and more current, its true kilowatt component remaining constant, and the generator with the decreased field will take less current. If it is assumed that the two generators continue to deliver equal true kilowatts the relative power-factors will vary in approximately the ratios shown by the following table:

Power-factor of Generator "A."	Power-factor of Generator "B."
70	70
80	61.5
90	54.1
95	50.3
100	44.0

P. M. L.

127—POWER-FACTOR—If the voltage lags behind the current in an alternating-current circuit, owing to the capacity of the circuit being greater than the induction, will the power-factor be equal to the cosine of the angle of lag or lead. W. C. P.

Power-factor is the ratio of power to volt-amperes. If both current and e.m.f. are of sine wave form the power is equal to the e.m.f. multiplied by the current in phase with the e.m.f. The component of the current in phase with the e.m.f. is the current multiplied by the cosine of the angle of phase difference, whether the current is leading or lagging; so that power-factor is equal to the cosine of the angle in either case. A leading current may be considered as having a negative angle or lag, and as the cosine of the negative angle is the same as that of an equal positive angle, this interpretation is correct from a mathematical viewpoint. H. W. B.

128—NEGATIVE POWER-FACTOR — I read the statement, "if the phase angle was greater than 90 degrees the power-factor would be negative." Under what conditions can this occur? Does not the voltage either lead or lag in reference to the current between the angles 0 degrees and 90 degrees, depending on whether the capacity or induction is the greater? W. C. P.

When a generator is connected to a circuit having in series only resistance, inductance and capacity, the current cannot be more than 90 degrees out of phase with the e.m.f., but if a synchronous motor (or a rotary converter or another generator) is in the circuit, the difference of the e.m.f.'s of the two machines sends current from the generator through the other machine. This difference of e.m.f.'s may have any phase relation to the e.m.f. of the generator above, and the current between machines usually lags behind the difference of e.m.f.'s by a small angle. For example, if the difference of e.m.f.'s is 90 degrees behind the generator e.m.f., and the current is 10 degrees behind the difference of e.m.f.'s, it is 100 degrees behind the generator e.m.f. Of course with this phase relation the generator is not delivering positive power to the other machine which, therefore, cannot run continuously without changing phase relation, or receiving power from some other source. H. W. B.

129—DOES A LOW POWER-FACTOR MEAN A LOSS OF ENERGY, that is, an overload on the prime mover, or does it merely result in limiting the capacity of generators, lines and motors, and cause a greater C^2R loss, due to the "wattless" amperes? R. H. F.

A given energy load at low power-factor imposes no greater load on the prime mover than the same energy load at 100 percent power-factor except for the greater copper loss in the electrical circuits due to the larger current flowing and other small losses in the generator. It does limit the capacity of the generator and all other parts of the electrical circuits since the capacity is determined by the prod-

uct of amperes and volts—that is, k.v.a.—as measured by ammeter and voltmeter and not by the energy—or kw—as measured by the wattmeter. See No. 78 in the May issue. The increased load on the prime mover, due to the increased losses in the electrical circuits is negligible from the standpoint of the prime mover capacity, but the increased current in the electrical circuits is a serious consideration and constitutes the chief objection to low power-factor loads. F. D. N.

130—MOTOR SUSPENSION, N. Y., N. H. & H. R. R. ELECTRIC LOCOMOTIVES — What portion of the weight of the motor is supported by the springs in the driving-wheel pockets and what portion by the driving-axle journals G. F. S.

The motors on the N. Y., N. H. & H. R. R. Co.'s locomotives are suspended by two independent sets of springs. One set, attached to the motor frame and a cradle supported on the journal boxes, carries the weight of the motor frame and about half the weight of the armature. The other springs are in the wheel pockets and act directly on the armature through the quills which are pressed into the armature spider. The forces that the driving springs are called upon to meet (aside from the driving torque) are the half armature weight and such variations of weight distribution as are brought about by the running conditions. S. M. K.

131—What is meant by "the CRITICAL SPEED" of a high speed turbo-generator shaft? This term is used in an article in the Proc. of the American Institue of Electrical Engineers on p. 12, Dec. 13th, 1907. It is stated that "the shaft at the center is very large so as to bring the critical speed well above normal." An explanation of the meaning of this term would be most interesting. W. F. M.

In a perfectly balanced rotor the center of gravity is in the axis of rotation. Imagine that by an external force the shaft is sprung slightly so that the center of gravity is not in the axis of rotation; then the centripetal (i. e. radial) forces, required to prevent an increase of this displacement during rotation, is proportional to the displacement and also to the square of the angular velocity. Now the force necessary for bending the shaft slightly is also proportional to the displacement. Hence there is some angular velocity or "critical speed" which just balances the centripetal force against the elastic resistance of the shaft, whatever the displacement may be; that is, with these ideally simple conditions, there is an unstable condition; and there may be wide oscillations of displacement, that is, marked vibration, due to even slight disturbances. Practically, such disturbances are caused by slight initial unbalancing, non-uniform elasticity of the shaft and supports, etc. On the other hand, the oscillations are damped by reason of imperfect elasticity of the materials, slipping of joints, etc., so that the oscillations seldom reach dangerous conditions. The stiffer the shaft, the higher the critical speed becomes. For steady running the critical speed evidently should not be near the normal speed of operation. A. K.

132—MEASURING THREE-PHASE POWER—If two indicating wattmeters are properly connected into a three-phase line and simultaneous readings are taken, their sum will indicate the total power in the line; but if only one wattmeter is inserted, the system being balanced, readings multiplied by 1.732 will give the power. This latter method apparently does not check the first. Please explain this. J. C. B.

The second method is wrong. At 100 percent power-factor the total power is equal to 1.732 E×I, where *E* is the e.m.f. *between two lines* (as measured by voltmeter), and *I* is the current *in any one line* (as measured by ammeter). It is obvious though that this current and e.m.f. are not in phase, even with 100 percent power-factor on the line, so that the product of volts by am-

peres does not give watts. With a lower power-factor than 100 percent on the line the difference between the product of E×I and the wattmeter reading is still greater. H. W. B.

133—ROTARY CONVERTERS VS MOTOR-GENERATOR SETS — Which equipment is the most desirable in transforming from 2 200 volts, alternating-current, 50 cycles, to 550 volts, direct-current, for use in running mill motors, cranes, etc. —rotary converter, synchronous motor-generator set, or induction motor-generator set —as regards efficiency, power-factor, and momentary overload capacity? C. A. Y.

In selecting an equipment for a given case the following characteristics of the three types of apparatus mentioned should be considered in order that a choice may be made which will best suit the conditions of operation.

Rotary Converter—When a large portion of the load is direct-current and when the machine is located on a transmission line, the rotary converter gives the most satisfactory arrangement. It has the best efficiency of the three types of machines and has a liberal capacity for power-factor correction. Moreover, the transformers used in stepping down the voltage on the transmission line effectively protect the machine against lightning disturbances. For the majority of cases the rotary converter offers the most advantages. There may, however, be peculiar conditions of operation which make desirable the use of one of the other arrangements as indicated in the following.

Synchronous Motor-Generator Set—When the operating conditions are such that the total induction motor load on the system is large or voltage regulation on the direct-current side, independent of the alternating-current voltage, is desired, this is the most advantageous arrangement. This machine has a larger capacity for power-factor correction than the rotary converter.

Induction Motor-Generator Set—When a large portion of the total load is direct-current and very fluctuating, and power-factor correction is not important, this is the most advantageous arrangement. If the peaks are excessive some form of equalizer is desirable. This machine has the maximum overload capacity of the three types and motor speed characteristics may be obtained which are suitable for a fly-wheel system whereby a fairly uniform alternating-current load may be maintained. B. W.

134—INDUCTION MOTOR—CHANGE IN CAPACITY—If the specifications for an induction motor call for a power-factor of 91 percent at full-load, 60 cycles, 2 200 volts; (a) what effect will a higher and a lower frequency and a higher and a lower voltage have on the power-factor and why? (b) If power is purchased on a basis of a power-factor of 91 percent (that is, full-load power factor) at X dollars per hp-yr., what will be the result if an induction motor has a power-factor of only 89 percent at full-load? X. Y. Z.

(a) If the frequency be raised or the voltage lowered, the power-factor of an induction motor of standard design will be increased and vice versa. The power-factor is the ratio of the true to the apparent energy input to the motor. The apparent input is the resultant of the true energy input and the wattless input. The wattless component of the apparent input is made up of two elements, the magnetizing watts and the leakage watts. With standard modern designs of induction motors, the relation of the leakage to the magnetizing watts is approximately one to two or one to three. By increasing the frequency within normal limits, the percent leakage is increased and the percent magnetizing decreased in approximately the same ratio as the change in frequency. As the magnetizing watts are a much larger percent of the wattless component than the leakage watts, the effect of increasing the frequency is to decrease the total wattless component. This in turn decreases the apparent input to the motor and thereby increases the

power-factor. By the same reasoning, a decrease in the frequency may be shown to decrease the power-factor. If the voltage of the motor is increased within normal limits, the effect is the same as decreasing the frequency and vice versa. The change in voltage, however, affects the leakage and magnetizing watts in proportion to the square of the voltage, the leakage watts decreasing and the magnetizing watts increasing with an increase in voltage and vice versa.

(b) A motor having a power-factor of 89 percent will have a full-load current approximately two percent greater than one having a power-factor of 91 percent. In order to obtain the same output from the two motors, the capacities of the generators, transformers, and line will have to be greater for the low power-factor than for the high power-factor motor. The exact evaluation of the difference in power-factor is practically impossible to calculate for a general case, as the elements entering into the calculation vary with different plants. For each case, the cost of the generating plant and line must be calculated per unit output and from this the effect of variation in power-factor can be approximately determined; the capacity of the generator and transformers and line being assumed as increasing in proportion to the decreasing power-factor. See articles in the JOURNAL by Mr. G. B. Werner, July, 1906, Vol. III., p. 401, and by Mr. J. W. Welsh, September, 1905, Vol. II., p. 551. R. S. F.

135—SHAPE OF SLOTS IN INDUCTION MOTORS—In two induction motors, identical in every respect except the shape of the armature slot would there be any material difference in speed and efficiency of operation or in the heating? The only difference in the shape of the slots is that in one case the aperture is only about 9/32 of an inch, that is, it is virtually a closed slot, whereas the other is an open slot with nearly a ½ inch aperture and notched near the mouth to hold the retaining wedge. A. W. R.

Induction motors identical in every respect except the opening of the slots would differ in the following points: the motor with the open slots gives a lower power-factor, lower efficiency and runs hotter at the same horse-power output. The speed is practically the same as for the motor with partially closed slots. The differences mentioned above may be of small or great amount depending mainly on the mechanical clearance between the rotor and stator, the number of slots and number of poles and the degree of saturation of the iron and current density in the copper. H. C. S.

136—STARTING TORQUE OF SINGLE-PHASE INDUCTION MOTOR—In the type of single-phase induction motors started by means of a phase splitter, what is the minimum angle required between the current in the starting winding and that in the running winding to obtain a sufficient starting torque? How does the variation of that angle change the torque, and in what proportion? When the power-factor of the line is very low is the angle obtained so small that there is no starting torque at all? G. DE LA R.

The starting torque of a single-phase motor with a split phase is approximately proportional to the product of the two currents and the sine of their angle of phase difference. That is, $T \propto I_1 \times I_2 \times \sin a$ where, T=torque; I_1=current in the main phase; I_2=current in the auxiliary phase, and a = the angle between the two currents. The torque varies with the sine of the angle; however, the size of the minimum angle required depends upon a number of conditions:

1—The torque that it is desired to obtain.

2—The magnitude of the currents flowing in the two windings.

3—The various design features of the motor which influence the starting torque, such as the number of turns in the two phases, the secondary resistance, the number of slots, etc.

It is therefore impossible to make

a general statement with regard to the minimum angle required. If the motor is started light, an angle of 20 degrees is very frequently sufficient. The power-factor of the line to the motor is always determined by the motor characterists and those of its auxiliary devices. If the ratio between the resistance and the reactance is the same in each circuit the angle between the currents in the two circuits is zero. This, however, may always be avoided. If the power-factor of the main phase is very low, the auxiliary phase may be supplied through an external resistance or capacity or, what is more commonly done in practice, the auxiliary phase may be wound with high resistance. R. E. H.

137—Protection From Lightning—An item recently came to my attention in which it was stated that no high tension transmission line was free from the effects of lightning, and that the large power transmission companies had not yet succeeded in solving the problem of lightning protection. This article apparently confined its statement to high tension lines but in conversation with several owners of relatively small systems of considerable length operating at about 6 000 volts, it developed that they also had trouble from the same cause and one of the men admitted that they did not yet know how to fully control the lightning. What are the facts? Is there any particular part of the line that is more subject to lightning discharges than others? Is trouble more liable to occur on the high parts of the line than on the lower? Can trouble be avoided by a proper preliminary survey or investigation of the system with a view toward lightning protection? J. H. H.

Transmission lines, whether they be operated at high or low voltage, alternating or direct-current, are more or less subject to trouble resulting from lightning and other static disturbances. It is supposed that on a line running through uneven territory the highest points are most susceptible to lightning disturbances. The possibility of avoiding difficulty in this regard by so laying out the system during the preliminary survey as to avoid any such unfavorable conditions, has been made the subject of some discussion. While it is conceded that favorable results might be obtained from these features such questions as the right of way and the advantage of directness of route, etc., are often more important considerations. A preliminary investigation of conditions without doubt makes it possible to obtain superior operation as a result of the proper provision for lightning protection and the fact that there are prominent consulting engineers who specialize in this direction, makes it apparent that this subject is receiving most serious consideration. In this connection, the article by Mr. R. P. Jackson on "The Protection of Electric Circuits and Apparatus from lightning and Similar Disturbances" appearing in the Feburary, March and April, 1908, issues of the Journal will be found most instructive. That the subject is one actively before the attention of electrical engineers is evidenced by the various papers that have been presented before the American Institute of Electrical Engineers during the past several months. See the following papers appearing in the Transactions of the A. I. E. E.: "Comparative Tests of Lightning Protection Devices on the Taylors Falls Transmission System," by J. F. Vaughan, also "Studies in Lightning Performance," "Season 1907," N. J. Neall, May, 1908; "Critical Study of Lightning Records on Taylors Falls Transmission Line," by Percy H. Thomas, July, 1908. R. B. I.

THE

ELECTRIC JOURNAL

VOL. V. SEPTEMBER, 1908 NO. 9.

Tirrill Regulators

A number of important points are brought out in the article by Mr. A. A. Tirrill on "Regulators for Alternating-Current Work" in this issue of the JOURNAL. Among these one which should receive more consideration is the use of Tirrill regulators for maintaining constant current, constant watts and constant power-factor. At the present time by far the majority of the regulators installed are for use in maintaining constant voltage, usually at the generator bus-bars. The success with which they perform this service is indicated by the large number of these regulators in use and the continually increasing demand for them. The field for their use as current and power-factor regulators is large, and results just as encouraging and beneficial have been obtained by the application of these regulators to this class of service.

The feature of this regulator and its point of difference from other types of regulators on the market, is the elimination of the principle of cutting resistance in and out of circuit by the step-by-step method. An examination of the elementary diagram shown by Mr. Tirrill will indicate the method employed, whereby the regulator accomplishes the purpose of voltage regulation by rapidly opening and closing a shunt circuit across the exciter field rheostat. The desired voltage is maintained by varying the relative proportion of time this rheostat is in circuit and out of circuit. In actual operation, the contact arm covers a full range of regulation by a movement of one-sixteenth of an inch. Other regulators are inclined to hunt, due to the fact that their regulator arms have to travel over a long range, and further because of the inertia of the moving parts. It is evident that there can be no such trouble in the operation of the Tirrill regulator.

Another use of the regulator which is often lost sight of is the application of the alternating-current portion of the regulator to compensation for line loss. The function of the series winding of the alternating-current magnet is to build up the generator voltage in direct proportion to the amount of current in the line. This com-

pounding effect can be varied as desired by adjusting a contact arm to include the proper number of series turns on the magnet and when once correctly adjusted, the regulator will maintain constant potential at the center of distribution without any hand adjustment.

For the successful operation of a Tirrill regulator equipment, it is necessary that there be enough resistance in the exciter field rheostat to attain a range in the exciter voltage sufficient to insure the proper percentage of regulation in the alternating-current generator voltage. The exciter voltage, particularly if the load is partially inductive and the regulator has to compensate for line loss, will vary from seventy to one hundred and twenty-five volts, and in order to obtain the full range of regulation within the scope of the regulator in such cases, the alternating-current generator field rheostat should be turned entirely out and the exciter field rheostat adjusted to lower the alternating-current voltage to about sixty-five percent below normal. Assuming the normal voltage on the secondary of the potential transformer used with the Tirrill regulator to be one hundred volts, the exciter field rheostat should be able to produce sufficient variation in the exciter voltage, so that the voltage in the secondary of the potential transformer could be reduced to forty volts.

The application of these regulators to the control of the voltages of direct-current generators, though not covering as wide a field, is just as successful in the results obtained. The principle is exactly the same, it being only necessary to rearrange the alternating-current portion of the regulator for direct-current serivce.

K. E. Van Kuran

Conservation of Power Resources

A three-fold increase in the horse-power used in the United States between 1870 and 1890 was coincident with a corresponding advance in industrial and commercial activity. A notable book which appeared near the close of this period entitled, "Recent Economic Changes," traced the underlying causes of the universal panic of 1873 to industrial and social re-adjustments which resulted from the introduction of the steam engine and pointed out the significance of the tremendous industrial expansion which had occurred in the decade and a half following 1873.

And yet the total power developed in 1890 is equalled by the electric power used to-day. The output of engines after a century is equalled by that of dynamos after a little more than two decades.

The total power doubles in about ten years, the electrical power in about five years. To-day the electric power is about thirty percent of the total power including that developed by waterwheels, stationary engines and locomotives. The total power is now thirty million horse-power and the electric power is nine million horse-power.

These interesting and significant figures are given in a paper by Mr. H. St. Clair Putnam, associate of Mr. L. B. Stillwell, in a brief on "Conservation of Power Resources," presented at the recent conference at the National Capitol. Historically, three steps of development are found: First, the direct utilization of water power, as in the early manufacturing plants of New England, which held ascendancy in manufacturing until about 1870. At this time the power developed by water and steam were nearly equal and the total was less than four million horse-power. Then came the development of the steam engine, of the railways, of coal mines and of commercial enterprises. This was followed by electric power, or rather the transmission of power by electricity, with its removal of limitations of distance and facility for subdivision of power generated in large power stations into an indefinite number of units. Hence the remote waterfall and the efficient ten thousand horse-power steam turbine, otherwise useless, became useful.

Mr. Putnam points out that our anthracite coal, at the present rate of consumption, will be gone in three score years and ten, and that the present rate of increase in the use of bituminous coal would exhaust it in a few hundred years.

On the other hand, the probable waste of water power in the United States is thirty million horse-power—equal to the present use of power—and some one hundred and fifty million horse-power could be made available by the use of suitable storage reservoirs. Mr. Putnam further points out that the proper development of our water systems in connection with inland waterways, canals, irrigation and water supply may be made in conjunction with power development to great advantage, as the regulation of stream flow by forest preservation and by reservoirs is a common essential.

The importance of power resources from another point of view is shown by the value of manufactured products per horse-power, which in 1905 was $1 152, and the wages, $248. The gross receipts of the railroads were $555 per horse-power and the wages $224. If the minimum estimate of thirty million horse-power of water-power were to be applied with corresponding wage rates, the wages involved in the utilization of this power would be fifteen billion dollars.

Some of these figures are estimates based upon more or less inadequate statistics. They serve, however, to give a perspective view of present tendencies. An increase of five hundred percent in horse-power in a single generation is a tremendous fact when it is remembered that the application of power lies at the basis of industrial and commercial activity. It is of first consequence to consider where this power is to come from in the future. Coal from which about ninety percent of the present power is produced is fast disappearing.

Electricity is an important factor in these larger considerations. It greatly increases the efficiency of the production and application of power from coal, largely by the substitution of large power stations for many small engines. It is electricity which makes possible the utilization of water power for general purposes.

The figures of Mr. Putnam which give the present increase in horse-power electrically applied as two million horse-power, while the total horse-power installed is increasing at three million per annum, shows the place which the electric motor takes in progress and indicates the probable future.

CHAS. F. SCOTT

Power Plant Layouts

The process of development of engineering methods from the first primitive conception of an idea to its final adoption in its ultimate form as standard practice is frequently characterized by changes and improvements which are little short of revolutionary in their results. It frequently happens that the latest development is hailed as an improvement which will result in the entire elimination of its predecessor. It is often found to be the case that each finds a field for which it is particularly fitted. This has been the case in the field of illumination, where it has been found that each of the various kinds of incandescent and arc lamps have well defined applications for which they are especially suited.

The article on "Double-Deck Turbine Power Plants" in this issue of the JOURNAL gives a description of a new type of station layout which, judging from the information presented, will be found a very convenient and economical arrangement in many cases. While it does not appear that the double-deck station will revolutionize central station practice, yet it seems probable that there will be found

many locations where this arrangement can be used to better advantage than the usual plan of having the turbine and boiler rooms on the same level.

In the matter of initial investment, while the stations mentioned are of comparatively small capacity, very low costs have been obtained. In the discussion of Mr. Bibbins' paper before the American Institute of Electrical Engineers, figures were given by Mr. C. W. Ricker, electrical engineer of the Cleveland Construction Company, designers of the station of the Youngstown and Ohio River Railroad, as to the cost of the West Point station. The total cost of the plant was given as $82.06 per kilowatt, divided as follows: Building and fixtures, $21.40; boiler plant, $14.24; condenser plant, $6.41; generating plant, $37.59; general expenses, $2.42. In explanation of the item for building, Mr. Ricker stated that the station is about seven miles from the nearest steam railroad point and the materials used in preparing the foundations and other concrete work, and all the steel for the frame and the crane had to be hauled that distance over bad country roads at an expense exceeding $1.00 per ton. The electric railway was completed to West Point in time to transfer the remainder of the material and machinery. It seems reasonable to suppose that a similar station could be duplicated in a location more favorably situated at a considerably reduced cost; so that taking into account also, the small capacity of this station, 3 000 kilowatts, the relative cost would not be far from that of the Fort Wayne station of $66.25 per kilowatt.

In this connection, it has been suggested that there are possibilities in another re-adjustment of the relative locations of power machinery in stations where power is generated by the use of producer gas plants with horizontal gas engine units. In this type of structure producers, scrubbers and all auxiliaries are placed on the second floor and engines of the tandem horizontal type on the first floor. In fact, it has been stated that a 16 000 kilowatt plant has been designed for a large city railway system in which the ground floor area was only about 2.25 square feet per kilowatt. In a building of this kind the structural steel work can be made comparatively light as there is practically no moving machinery in the gas generating plant.

The double-deck stations which have been built seem to be especially economical in the matter of first cost. It will be interesting to learn how they compare with other stations as to actual operating results and maintenance.

A. H. McIntire

Connections for Synchronizing

In the article on "Meter and Relay Connections," by Mr. Harold W. Brown, in this issue of the JOURNAL, standard connections and arrangements of apparatus for synchronizing are shown and explained. It is important that the operations required in synchronizing be as few and simple as possible. In fact it is more important that the number of operations required of the attendants be reduced to a minimum than that the scheme of wiring be reduced to its simplest form. After the apparatus is installed and permanently connected, the operator gives attention rather to the manipulation of the plugs and switches than to the scheme of connections.

In the majority of stations the arrangements for synchronizing are comparatively simple; but occasionally a synchronizing system is desired which will make possible a number of different operations. By means of combinations and enlargements of the arrangements explained in Mr. Brown's article, with perhaps in some cases the addition of auxiliary switches or receptacles and plugs, it will be found possible to arrange for almost any conditions of operation which may be desired. In all cases it is desirable, not only to reduce the number of switching devices to a minimum but also to so interconnect them that the sequence of operations necessary during the process of synchronizing will be the least liable to confuse the operator.

With high voltages it is important to reduce the number of shunt transformers to the smallest number possible. It is customary to use oil insulated transformers mounted, along with their primary fuses, in individual compartments and hence from a cost consideration alone their number should be reduced to a minimum.

As indicated in Mr. Brown's article synchronizing of polyphase circuits is accomplished by synchronizing one phase of the incoming circuit to the corresponding phase of the circuit with which it is being paralleled. On two-phase circuits where the generators have the middle of phase $A_1 A_2$ connected to the middle of phase $B_1 B_2$, it is possible to synchronize across $A_1 B_1$. This is not usually a convenient method, however, as the voltage obtained is approximately seventy percent of the normal voltage, thus practically necessitating specially wound synchronizing apparatus and special lamps.

When synchronizing receptacles are used on circuits controlled by electrically-operated oil circuit breakers, it is customary to have an extra set of contacts on the synchronizing receptacles which close

the control circuit of the circuit breaker when the synchronizing plug is inserted. This feature makes it impossible to close the circuit breaker without first inserting the plug connecting the circuits to be synchronized, thus minimizing the danger of accidentally connecting generators together without synchronizing. While the control circuit of the circuit breaker passes through the extra contact of the receptacle, the tripping circuit does not, and hence the circuit may be opened independent of the position of the synchronizing plug.

In large installations indicating lamps with red and green lenses are mounted on the control desk or switchboard panels. These are usually arranged so that a red light indicates a closed switch and a green light an open one. Some engineers prefer to use red indicating lamps to indicate the open instead of the closed position of the main switches, their argument for this being that an open switch is more dangerous than a closed one; that is, that the thoughtless closing of a switch may bring far worse results than the accidental opening of one. Where the connections are complicated, it is customary to place a miniature bus-bar on the switchboard and to locate the indicating lamps so that they indicate on the miniature circuits the actual connections of the main circuits. The use of these indicating lamps and miniature bus-bars greatly simplifies the work of the switchboard operator in a large plant as he can see by a glance at the miniature indications which switches are closed and which are open. As the extra cost of this arrangement is comparatively small, it is usually considered well worth while. The switchboard operator of a large station often has under his control machinery worth many thousand dollars and hence any devices or arrangements which will prevent mistakes may be considered good insurance. As to the operation of synchronizing, even with elaborate interlocking and safety devices, the only absolutely "fool-proof" device is the automatic synchronizer.

C. H. Sanderson

ENGINEERING PERSONALITY AND ORGANIZATION*

WALTER C. KERR,
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I HAVE a few words to say to you about engineering individuality and organization; about the breadth of the man and of organizations; about team work; also regarding the conditions through which each man reaches his fullest capacity for the performance of his best effort; and the suggestion that you keep your eyes so wide open, and your perception so clear, that you can sense in advance the training requisite for the final attainment.

No definition of individuality, nor yet of organization, seems necessary. They possess points of similarity and of difference. The individual, whatever be his traits, is always a part of a complex organization—in fact many organizations. He is a part of human kind, of society, of a group of more or less like kind as in a profession; he is part of the organization of a nation, of a state, and probably of a municipality. At no turn can he get away from his part and companionship in organizations of many kind. He has duties to render to all. But it is not thus broadly I refer to organizations in this brief discourse. I am limiting the consideration to individualism in engineering and organization work as carried on by groups of engineers. Individualism has to do with the performance of a man himself. Organization has largely to do with what he shall perform, and what shall be the result of his performance, especially as related to cognate branches and other human effort.

An engineer should be an idealist from youth to maturity. He must aspire to high position among men. He must, through his developed capacity, grasp and control the inter-relationship of everything concerning an undertaking from conception to use. This grasp embraces the adaptation of all the varied branches of engineering to produce the ultimate results required in complex projects, and a special or expert knowledge of the predominating requirements. It should also cover a broad conception of finance, the accepted methods of procuring and accounting for funds, and a clear idea of the operation of properties after their installation.

With such an ideal clearly in mind, its attainment necessitates the appreciation that it cannot be achieved in a day, nor without long

*An address before the graduating class of Rensselaer Polytechnic Institute, June, 1908.

and varied practical experience. It must be sought with energy and discretion, and with earnest cultivation of breadth of view, character, integrity, healthful living, and useful recreation.

It is not given to all to realize their complete ideals, but as far as you are able to go you should make the results good.

No time can be more important or interesting to a young man than that in which he begins to apply himself usefully to his world, as he sees it. He will consciously or unconsciously shape himself to some general line of action, which will result in his becoming a certain kind of man or type of engineer, regardless of the particular operations to which his talent is applied.

We all see things somewhat differently. We are all, more or less, creatures of present influences and previous conditions. The previous condition of any man, with reference to any thing, largely shapes his view, opinion, and action concerning it.

When the man reared on the mountain and the inhabitant of the valley view the plain, their impressions are quite dissimilar. Between the man accustomed to frontier hardship and one accustomed only to the luxurious ease of metropolitan centers, there will arise divergent views concerning the common plane of average surroundings. Thus labor and capital are liable to be arrayed against each other, though their interests are really common. Many differences in the world arise mainly through divergence in view, following upon difference in previous condition.

It thus becomes easy to appreciate how men of about the same ability and influence differ in expression and action. What is often called reconciliation of views or opinions is, therefore, largely the bringing about of a similarity of mental attitude toward them. Tenacity of opinion is often only tenacity of position. Men seldom change their opinions so long as their view-point remains constant, but the broader the man the wider his angle of vision. The all-around judicial type lives on a mental plain in which he can circumscribe any problem, see it from many sides, and from his different views select the most important.

You have all grown up under quite similar conditions, and having been educated together you start into the world from about the same previous condition. You have been taught the same things that other civil engineers have learned. You have absorbed much of the conventional methods of procedure, varied perhaps with a few odd strokes of originality which surpass the conventions. You have learned more or less of the traditions of an old and honored pro-

fession, and, as is usual, you have become largely the center of your own world.

There has not as yet been much to remind you that the world is full of conditions that you have not met, of men of a type you have not known, of motives that have not been stimulated by your training, of a world full of engineering that is not static; nor have you yet met complexities and perplexities which not only require great skill and ability to handle, but which may call for combinations of human effort the realization of which has not been awakened, nor could it well be, by your previous condition.

However much you admire the achievements of the civil engineers of the past, you are more interested in correctly grasping the missions of the engineers of the future. While fundamental principles are fixed, men and methods are undergoing constant evolution.

Every young man should realize that all of the manifold organizations of which he will in one form or another become a part, are ever changing. We admit that principles never change, but it is sometimes very difficult to detect whether a so-called principle is a natural and inviolable one or merely an artificial product, especially of custom.

If there is any one thing more than another which I would say has any profound bearing upon the ability of a capable young engineer to succeed broadly in his profession, it is the correct appreciation of the relation between what he can render through his talent and that rendered by engineers of dissimilar kinds through the exercise of their talents. This underlies the relation of individual effort in team work.

Narrowness is largely singleness. Breadth is multiplicity, hence versatility. Narrowness and personal conceit are companions. Breadth and versatility lead to modesty, yet often and usually coupled with that self-confidence which makes a man a strong advocate of that which he believes.

The time was when all of the profound engineering of the world was static. The only engineer, whether called military or civilian, therefore, was the static engineer. Dynamical engineering was in its infancy, and a trade rather than a profession. The broadening field remained within the prerogative of the civil engineer, who therefore was pre-eminently the man who practiced the profession so aptly termed "the art of directing the great sources of power in Nature for the use and convenience of Man."

An expanding world with its ramifying developments caused

differentiation, which led to specialization, and there became many kinds of engineers, who, in the aggregate, possessed the talents which the typical engineer should possess.

The field became too diverse for the individual man to encompass, and this led to the unwieldy, undesirable, and somewhat impractical division of labor and responsibilties which for a generation or two has existed.

The authority vested in the man, providing he exists, whose breadth and talents cover all the requirements of great diversified and complex engineering undertakings, offers a more practical means of performance than its segregation among the many.

But we must deal with men as they are, and the fact is that the necessities of great undertakings have so far outrun the individual that their performance demands a new type, an organization constructed in such a way as to combine all of the talents and restrict the limitations of the many, which shall exercise the necessary judgment and control.

All engineering operations are carried on through organization. The differences lie only in degree. The engineer with one man to help him is the simplest form. When an engineering corps is organized, the degree is raised. A large corps becomes complex and needs management, and when it grows so large as to be divided into squads containing men of different talent undertaking unlike work, real organization methods have been adopted. When this is further extended and made permanent for doing divers things for many people, instead of forming for an undertaking and disbanding when through, we have the type of permanent organization which may be called the new engineer.

The creation of this new type of engineer is the latest phase of engineering development. It is rather less than a quarter of a century old, and in high effectiveness perhaps not more than a dozen years.

This new type is not merely an aggregation of men, but a real organization; organized slowly, just as men grow; correlated slowly, just as men become educated; made effective by long processes of joint action and joint experience; rounded to a degree scarcely possessed by any individual, through the abrasion by contact of personalities differing sufficiently to shape each other, yet not enough to create friction.

This process has now been continued until there exist a number of such engineering organizations, in the ranks of which are found

civil, mechanical, electrical, and hydraulic engineers; also those versed in the special arts, such as lighting, heating, ventilating, machine tools, and compressed air. With these are associated men equally versed in thermodynamics, chemistry, statistics, architecture, law, and commercial affairs. Such organizations naturally also have the contingent following of draftsmen and assistants of all required kinds and talents.

Such an organization, even when composed of hundreds of individuals, acts—under proper management—virtually as one man. Its capacity obviously becomes great. On a given project, the various divisions can be worked up in parallel—it being the mission of some to see that the different kinds of work are constantly correlated, and that when the work has developed to a certain stage there are provided numberless hands and feet to attend to its performance.

This is one phase of the modern engineer which has grown, unconsciously, by force of necessity rather than by specific intent. It has the capacity to create a property from inception to operative finish. It is always ready at a moment's notice to undertake work of any kind and magnitude. It is always available for emergencies. It has grown in response to the demands of complex physical properties, which need to be created as a whole—with equal skill devoted to all their widely differing functions, which are too intimately related to be served by men whose work is not correlated by organization.

Financiers and others who must carry the prime responsibility for the creation of the largest works desire to lean on the fewest individuals, and as the complexity of their work would demand many personalities they naturally seek firmly developed organizations which so combine these personalities that they can lean on the group as on a man.

It is frequently remarked that large work, costing millions of dollars and extending over a period of years, suffers a needless hazard when entrusted to an individual, who might die, or be incapacitated by severe illness, or even possibly become mentally less competent as the work progresses. From these limitations, organization is the safeguard.

Such organizations in general comply with the usual conventions and practice of the respective types of engineers employed. They contain ample demonstration of the strength of unity.

Parallel with the growth of such organizations, there has been another development which might seem contrary to precedent, but which on closer analysis will be found to be rather a return to first principles. It is the performance by such organizations of constructive work, this being performed for a fee in the unselfish spirit of engineering service, and not in the speculative or selfish spirit of contracting.

In the recent past, it became usual for engineering work to be designed by the highest talent, but executed through common and almost unskilled labor. Further development constantly necessitated higher grades of skill in performance, and a closer supervisory conduct of the work by the engineer. This process continued until the time came when much of the performance of the work was of exactly like kind with its design, and in order to get it correctly performed the engineer needed to put his hand to the work itself. This began chiefly in dynamic lines, and has extended to others.

I think the time has about arrived to conceive of engineering as beginning with contemplation and passing through design and specification to and through construction and placing in operation, with no change of hands and with no break in the continuity of direct engineering control of the work itself.

This view one often hears unconsciously voiced by an engineer who, after all kinds of trouble and excess costs through contractors, says: "Give me the workmen with a few foremen and superintendents and I will do the work myself and do it right, on time, and within the estimates."

One of the Stevensons of Edinburgh, a family famous in engineering work for more than a century, said: "The duty of the engineer is two-fold—to design the work, and to see the work done."

There have been too many artificial divisions as to where one type of effort should stop and another begin. A principal one of late generations has been the line between design and construction. This is not a natural division, but a purely artificial one, born perhaps of the practice of meeting the conventional views of a given time. Times change, however, practice varies, and it becomes easy to see that what may have appeared like natural divisions are after all only artificial.

A parallel to this lies in what we call the natural order of plants. We are taught in botany to regard these natural orders as divided from each other by natural lines, and we therefore refer to the natural divisions. A moment's reflection, however, will indicate that

there is simply a natural sequence from the lowest to the highest, in which man has drawn artificial lines for convenience of classification, and thereby divided from each other certain orders which possess more or less like characteristics. It is the sequence which is natural and not the orders. So in engineering, from inception through to finished construction, there is a natural sequence to performance, rather than natural dividing lines. Keep your eye on integration, rather than differentiation.

The burden is upon every engineer to do his work right, not merely to design it right and let some one else do it wrong. He may utilize any means of assistance, by contractors or otherwise, but if through such assistance he cannot get proper results, he must be able and willing to put his own hand to the work and bear his burden. The frequency with which assistance fails leads many by experience to do their work at first hands, and organizations of engineers largely follow this method in the interest of quality, economy, and time.

The importance of this to the young man is that with each passing generation a considerable change takes place in all modes of procedure, and it is not to his advantage to find that methods have changed while he is asleep. He should be alert to see what changes are coming and judiciously meet those which are real.

I use this development of the engineering organization as illustrative of a change that has come, and it is indicative of others. Among these may be briefly mentioned the fact that the individual engineer, as he becomes broader, is becoming more of a factor in affairs. His advice is sought in things other than engineering, yet more or less related. He is constantly growing more into the counsels of men of other vocations, and will stay there just in proportion to the degree in which he is helpful.

A corroborating feature in the quality of this development is the cycle through which it returns to the simplicity of first conditions. Early architects designed and constructed. Early engineers designed and constructed. Both grew with the advancing arts. Differentiation occurred. Professionalism arose. The professional man ceased to construct. Further advance caused professional specialization. Creative forces scattered from the man to the many. Organization has brought together these personalities and, through well-ordered means, returned in effect to the individual. The individual, then, through this effective organization, constructs, and we

are back again to the early days in which the architect and the engineer both designed and constructed.

It was Emerson who called attention to the difficulty of stating one truth without violating some other. It is thus difficult to discuss the qualities of organization without giving rise to some misapprehension.

I especially do not wish to imply that organization displaces or absorbs personality. Let no man fear that in entering an organization he is sacrificing his individuality. Individuality is not limited by organization, but the means of individual expression become changed. A man cannot be a bad man and a good engineer. He may think he can, but he cannot. A man will find his level, be it high or low, more quickly in organizations than elsewhere. His qualities and limitations become better and more quickly measured.

The necessity for the development of engineering organization does not mean that the day of the single-handed engineer is over, though it must be admitted that the years as they pass are constantly surrounding him with additional limitations. There are men who are better fitted for individual effort than for what is generally called organization work. There is also a great field for their effort. It is fortunate that all men are not alike, and that all work has not the same characteristics and requirements. With the immense growth of material things, there has become such a diversity of operations that there is room for every type of man, every kind of temperament, and every form of good organization.

Each man needs to perceive where he fits best and to follow that in which his experience, and perhaps his opportunity, indicates the greatest hope of achievement, but nothing can be worse than for a man to fail to realize that there are many paths, some similar, others widely unlike; that there is room for all; that all work to a common end; that some ways are better than others for achieving certain types of excellence; and that the inferior result in mediocrity or failure. Many a man has made a signal success of his life working single-handed. Others who would have thus failed have done creditably well in organizations where their best talent could be conserved, their weakness supplemented, and their limitations safeguarded.

The high specialization necessary for great profundity in any one branch of engineering tends to limit the capacity of the individual in the practical conduct of work, but not so when he exercises his effort through an engineering organization. For this reason, I

believe the ablest engineers, to accomplish their ambitions most surely within the comparatively few years alloted to a man to work at his best, will prefer to identify themselves with organizations which carry, without their individual effort, the major burdens of physical operations, so that their portion of profoundly skilled service can be rendered into the largest volume of work.

There is much difference between things and the names of things. Thus organization is to many a name, but if any one will spend a quarter of a century developing an organization he will find that the name can be forgotten, except for convenient use, and his thought will turn to what it means to perfect an organization and make it effective. It is not sufficient merely to bring talented men together. Men who are individually effective are often ineffective when grouped. Talent alone is not sufficient, but temperament and personality are factors of the utmost importance in the necessary correlation of team work.

The relations of engineers with each other and of engineering organizations should be non-competitive. The word "competition" is too much used. It has a wrong ring. Engineers, like educational institutions, should each wish to excel, but not to the detriment of others. Thus they should treat with each other in the spirit of helpfulness, discarding all rivalry and jealousy. This not only conduces to the welfare of all and to the good of their work, but its free exhibit is inspiring to clients.

I am glad to see that this institution has broadened its scope to include other engineering beside that which it has taught longer than any other institution in this country. The reason this was done is that the day had come for it, and with the time there always comes the man to lead it. The day has quite passed for the classification of the different kinds of engineering, and keeping them apart as segregated world's functions. The growth of innumerable arts and the breadth of their application have produced a complexity which cannot be unraveled in the name of any one type of engineering performance.

A man studying one branch of engineering can acquire much knowledge of other branches through contact. This contact requires the presence of men and facilities, a broader world, in which a man principally acquires that for which he strives, but also much that is useful which rubs off against him.

Some men have apparently great discernment for seeing about half way through things. In nothing more than in engineering is it

necessary to see all the way through. This capacity is not altogether a matter of age and experience. It is born in some and cultivated in others. To see all the way through requires contact with all that is to be discerned.

Ability to cerebrate has not materially increased in the past two thousand years, but ability to get facts has. This marks the difference between logic founded on the intellect and that based on laws, facts, and real knowledge. The engineer starts from the latter, and if he will safeguard his facts his logic will not go far wrong. In one sense it may be said that a man's horizon extends as far as he can see, while his radius extends only as far as he can act. You need to broaden the one and lengthen the other.

Every young man should realize that the way about which he has been thinking may be outclassed by a way that has not occurred to him, and should keep an open, wholesome, and receptive mind regarding all relationships in the world and all methods of performance, with a discerning eye to the advancement of method as the world passes from decade to decade, and to read the handwriting on the wall just a little before it is written.

Whatever exertion you may be willing to make to use your knowledge in the rendering of your engineering skill, do not neglect to use your personality. This counts for much. You may not be conscious that you use it at all. You cannot prevent its use, for your personality will surely make some impression upon every one with whom you come in contact. If it is not the kind you particularly approve, change it all you can. If it is the kind that others do not seem to approve, it is your particular duty to suppress some of it and shape the balance.

Let every young man, therefore, with his strongest personality, his best personal effort, and with great confidence in his own resources, co-operatively join hands with his fellow-engineers and fellow-men in whatever manner seems, from time to time, to best render the service needed, and this will be most effectively accomplished when performed in the spirit exemplified by Abraham Lincoln, who, in his great breadth of wisdom said: "You may do what you please with me so long as it is for the good of the cause."

REGULATORS FOR ALTERNATING-CURRENT WORK

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THE great importance of good voltage regulation on alternating-current systems has long been recognized in all classes of alternating-current plants. While the regulators described below are two of the types most universally used for maintaining either constant voltage at the center of distribution or at the generating station, these regulators can also be used for maintaining constant voltage at the receiving end of the line in combination with synchronous motors at that point, the regulators in this case being connected to the synchronous motors to regulate in the same way as though the motors were used as generators. Tirrill regulators can be built for alternating-current work to maintain constant currents,

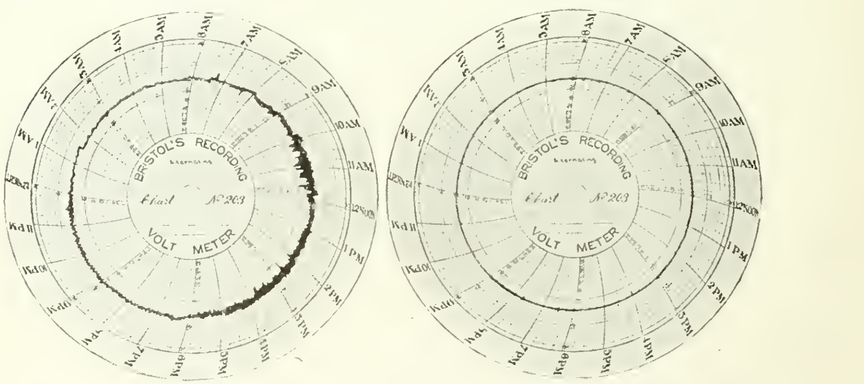


FIG. 1—VOLTAGE CURVES TAKEN ON THE CIRCUITS OF THE ST. JOHNS RAILWAY COMPANY AT ST. JOHNS, NEW BRUNSWICK

constant watts, constant power-factors or other special conditions. The regulators treated in this issue are two well known standard types for alternating-current work.

First—The TA Form A-2 which has been the standard type of regulator for small capacities for the past seven years.

Second—The TA Form F-2 to 12 regulators, which are of larger capacity, but similar to the TA Form A-2 in their operation.

Charts taken from the combined railway, power and lighting system of the St. Johns Railway Company's plant at St. Johns, New Brunswick, are shown in Fig. 1. The curve at the left was taken

before the installation of the regulator, while the curve at the right was taken afterwards. By referring to the latter, the advantage obtained by using these regulators can readily be appreciated. A

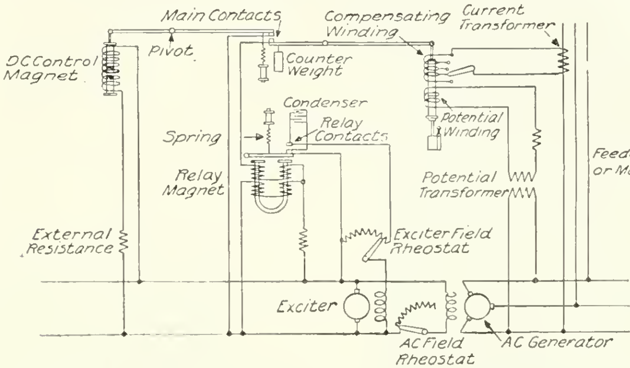


FIG. 2—ELEMENTARY DIAGRAM OF THE TYPE TA FORM A-2 REGULATOR

further appreciation of the success of these regulators is evidenced by the fact that there are at present over 2 000 of them in use, regulating plants varying in capacity from 25 to 40 000 kilowatts.

METHOD OF OPERATION

The voltage regulation is obtained by rapidly opening and closing a shunt circuit across the exciter field rheostat. An elementary diagram of the TA Form A-2 regulator is shown in Fig. 2. This shows an alternating-current generator, an exciter and the regulator. The latter has a direct-current control magnet and a relay. The control magnet is connected to the exciter bus-bars. This magnet has a fixed stop-core at the bottom and a movable core at the top which is attached to a pivoted lever, at the opposite end of which is arranged a flexible contact. Opposite this magnet is the alternating-current control magnet which has a potential winding connected by means of a potential transformer to the alternating-current generator or bus-bars; it also has a compensating winding which is shown connected to a current transformer placed in the principal lighting feeder. The compensating winding is adjustable so that any degree

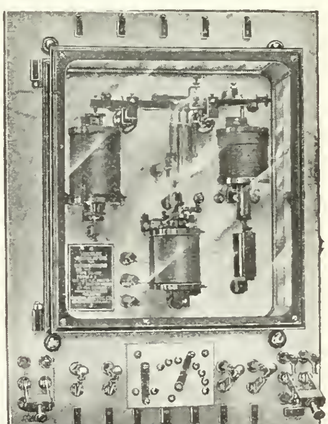


FIG. 3—FRONT VIEW OF THE TYPE TA FORM A-2 TIRRILL REGULATOR

of compensation may be obtained from one to fifteen percent, depending on the line requirements. This magnet also has a movable core attached to a pivoted lever; at the opposite end of this lever is attached a contact which, in combination with that on the direct-current control magnet lever, produces what is known as the floating main contacts. These contacts control one group of the differential windings of the relay while the other windings of the relay are, as shown, permanently connected across the exciter busbars. The relay windings shown have a U-shaped magnet core, and a pivoted armature which controls the relay contacts. These contacts are connected across the exciter field rheostat. To prevent destruction of the contacts, condensers are connected as shown.

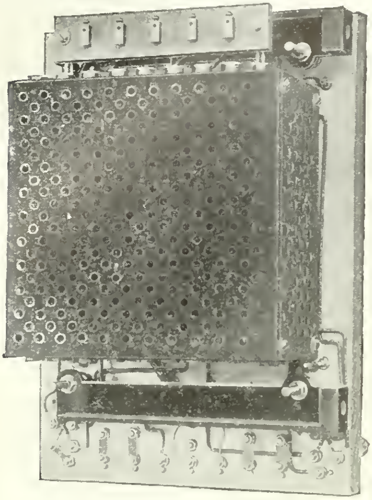


FIG. 4—BACK VIEW OF TYPE TA FORM A-2 TIRRILL REGULATOR

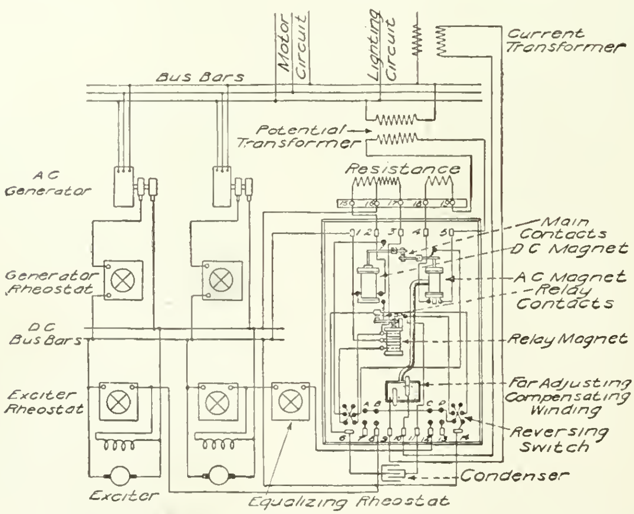


FIG. 5—DIAGRAM OF INTERNAL AND EXTERNAL CONNECTIONS FOR TYPE TA FORM A-2 REGULATOR

CYCLE OF OPERATION

The cycle of operation is as follows:—The shunt circuit across the exciter field rheostat is opened by means of a single-pole switch

at the bottom of the regulator, and the exciter field rheostat turned to a point that will reduce the alternating-current voltage to 65 percent below normal. This operation will weaken the alternating-current control magnet and its core will fall and make contact with the upper main contact carried by the direct-current main control magnet which has also been weakened so that the spring has pulled the direct-current magnet lever down, thus causing a permanent closure of the floating main contacts. This closes the circuit of the other windings of the relay which oppose the permanently connected wind-

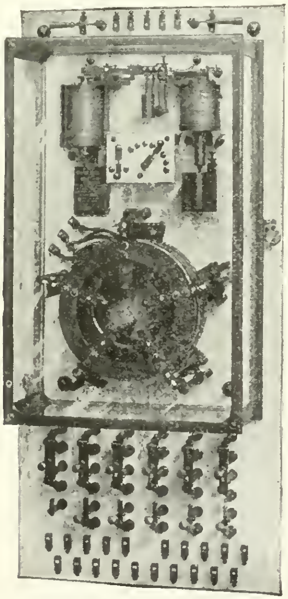


FIG. 6—FRONT VIEW OF TYPE TA FORM F-5 TIRRILL REGULATOR

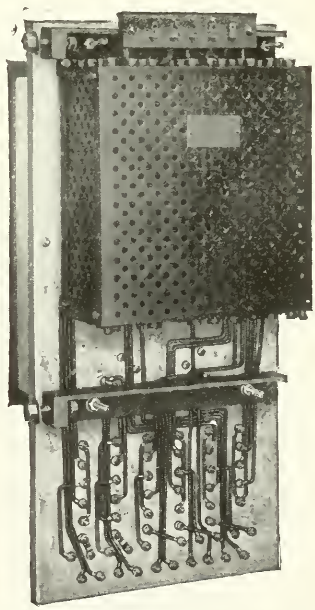


FIG. 7—REAR VIEW OF TYPE TA FORM F-5 TIRRILL REGULATOR

ings and demagnetizes the relay core, allowing the armature to be released and causing the closure of the relay contacts due to the spring connected to the armature. Then by closing the single-pole switch and thus allowing the relay contacts to short-circuit the exciter field rheostat, the voltage of the exciter will immediately rise and also the voltage of the alternating-current generator. As these voltages rise the alternating and direct-current control magnets will be strengthened and at the voltage for which they have been previously adjusted, the main contacts will open, thus opening one set

of the relay windings, giving the other set of windings full energy to magnetize the core, which overpowers the relay spring and opens the relay contacts, thus throwing again the full resistance into the exciter field current, which tends again to lower the voltage. This cycle of operation is continued at a high rate of vibration, due to the sensitive direct-current control magnet. Thus, not a constant, but a steady exciter voltage is maintained which will be increased or decreased according to the demands of the alternating-current system,

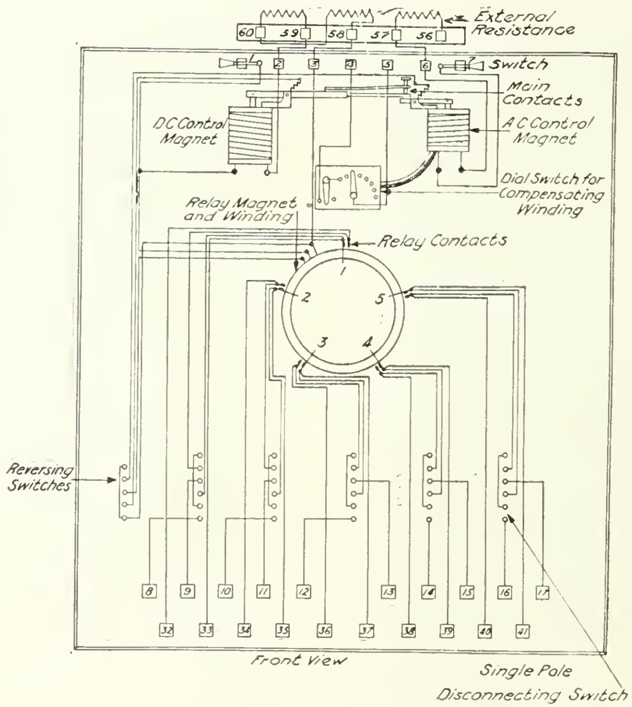


FIG. 8—INTERNAL CONNECTIONS FOR TYPE TA FORM F-5 REGULATOR

which tends to weaken or strengthen the alternating-current control magnet and thus maintain the desired alternating-current voltage.

DESCRIPTION OF TYPE TA FORM A-2 REGULATOR

A front view of this regulator is shown in Fig. 3, and a back view, showing the resistance box and iron brackets in position, in Fig. 4. This regulator is designed for use with alternating-current generators having exciters of small capacity. Fig. 5 shows the com-

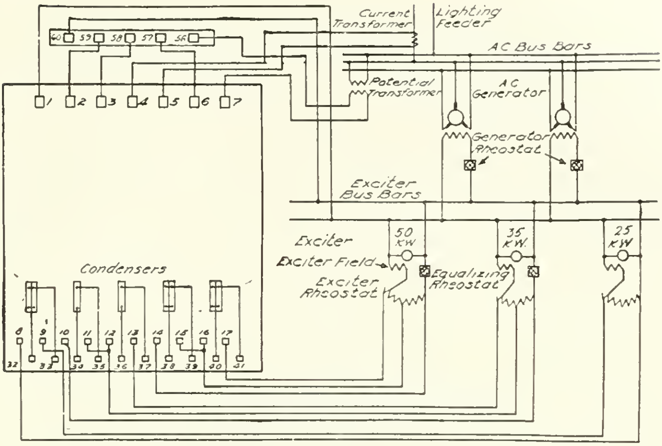


FIG. 9—AN ARRANGEMENT OF EXTERNAL CONNECTIONS FOR TYPE TA FORM F-5 REGULATOR

plete internal and external connections of this regulator to two exciters and two alternating-current generators, the exciters, as well

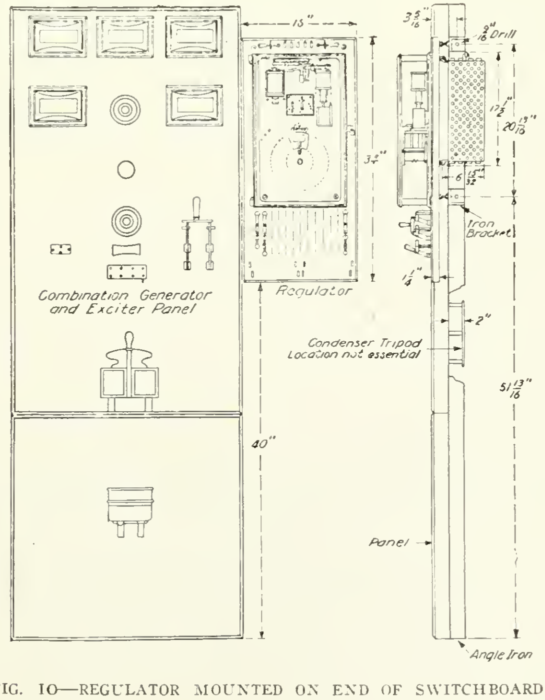


FIG. 10—REGULATOR MOUNTED ON END OF SWITCHBOARD

as the alternating-current generators, being operated in parallel. The exciters may be either shunt or compound-wound.

DESCRIPTION OF TYPE TA FORM F REGULATORS

A front view of a Type TA Form 5 regulator is shown in Fig. 6, and a back view in Fig. 7. These regulators are designed with relays varying from two to twelve, depending on the size, capacity and characteristics of the exciters used. The principle of operation

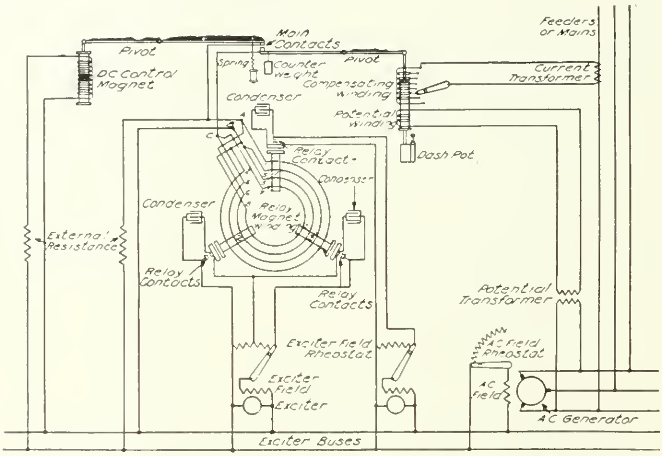


FIG. 11—ELEMENTARY CONNECTION DIAGRAM OF TYPE TA FORM F-3 REGULATOR

of these regulators is the same as the Form A-2 previously described. Fig. 8 shows complete internal connections of the Type TA Form F-5 regulator, while Fig. 9 shows one arrangement of the external connections of this regulator. From this it will be seen that many combinations can be made with this type of regulator to meet the requirements of different plants. These regulators may be mounted, in the same manner as the TA Form A-2 rgulator, on brackets at either end of the switchboard or on the front of a switchboard panel.

The method of using this regulator mounted on rigid iron brackets at the end of the switchboard is shown in Fig. 10. This arrangement, however, is not to be recommended, as the regulator should always, if possible, be mounted directly on the switchboard.

LINE DROP COMPENSATION

Line drop may be compensated for either by using a current

transformer as shown in Fig. 11, or as shown in other standard diagrams covering these regulators. With this compensating device there is a slight error due to changes of power-factor. This error is not sufficiently great to be a serious matter in ordinary installations. However, where greater accuracy is desired, a special line drop compensator is made for use with these regulators connected to the line as shown in Fig. 12. With this arrangement there is a

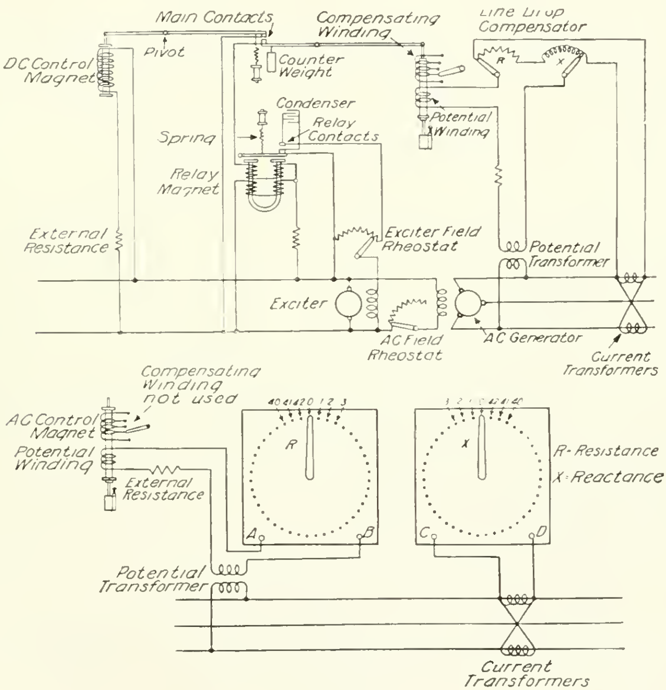


FIG. 12

resistance and reactance used which have taps brought out so that an artificial line can be produced by means of the dial switch levers. The constants of the artificial line can be made equivalent to the constants in the main line. With this arrangement of line drop there is no error in voltage due to changes of power-factor. The effect of capacity of the line is compensated for as well as the inductance and resistance, with loads of varying power-factor.

ELECTRIC RAILWAY ENGINEERING—VIII

A STUDY IN GEAR RATIOS

N. W. STORER

WHEN the history of the evolution of electric railroads is written, there will be considerable space devoted to gears and gear ratios. After the motor itself there is little, if anything, in the car equipment of more importance than the gears. A recent editorial in an English journal says that "motor gearing may be considered as an illustration of the survival of unfitness." This

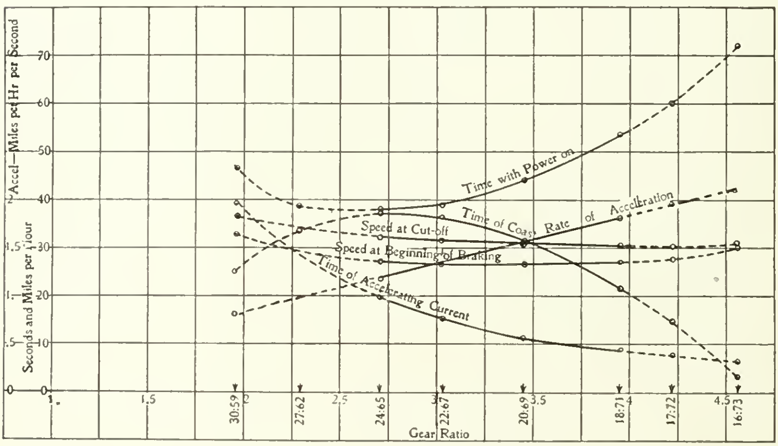


FIG. I—PERFORMANCE CHARACTERISTICS OF 40 TON CAR WITH DIFFERENT GEAR RATIOS WITH A CONSTANT ACCELERATING CURRENT OF 138 AMPERES PER MOTOR

remark is the result of a narrow view of the subject and does this very useful feature of the car equipment a great injustice. It is true that it is unsafe with many of the larger railway equipments to put gears in service and then forget them. It is equally true that most of the trouble with gears has been the result of bad design, improper application, small capacity or neglect, just as much as these causes have influenced troubles with other parts of the equipment.

The selection of improper gear ratios for railway motor equipments has alone caused a loss of hundreds of thousands of dollars to the operating and manufacturing companies in this country. Motors have been overloaded and burned out by the thousands. Fifty horse-

power motors have been used where forty horse-power motors would have done equally well if properly geared. Power houses and sub-stations have been overloaded, have had their load factor greatly decreased and the line loss has been greatly increased, simply because the motors on the cars have been geared for too high speeds. Few people who have not made a special study of the subject realize its importance, and at the present time, in spite of the campaign which has been waged against it by the manufacturing companies and a few enlightened engineers, there are still a good many motors in ser-

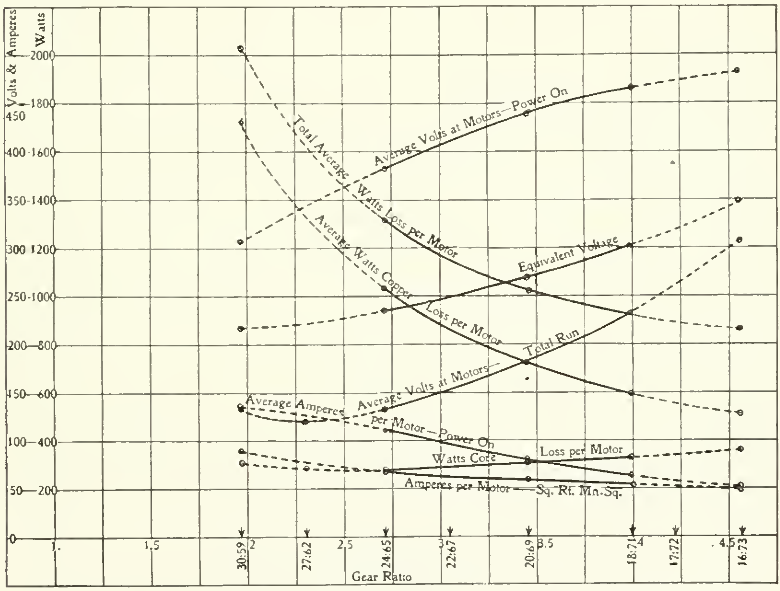


FIG. 2—PERFORMANCE CHARACTERISTICS OF 40 TON CAR WITH DIFFERENT GEAR RATIOS WITH A CONSTANT ACCELERATING CURRENT OF 138 AMPERES PER MOTOR

vice which are so geared as to result in a continual loss to the operating company. The large companies have been realizing more and more in recent years the disadvantages of high speed gearing and some of them are now making wholesale changes in their gearing, reducing the maximum speeds and making savings of five to twelve percent in power consumption, besides greatly reducing the temperature of the motors.

It is frequently the case that the motors are required for mixed service, city and suburban, and it is desired to operate at high speeds in the suburban districts, and the motors are therefore geared for

these high speeds, regardless of the fact that the most of their operation is in the city district where high speeds are entirely impossible. If certain cars could be set aside for this mixed service, it might not be so bad, but standardization is aimed at by all up-to-date companies and this is frequently carried to a point where all cars have the same gear ratio, regardless of the service for which they are used. Where this gear ratio is fixed by the high speed service, it means that larger motors must be used and more power consumed than is necessary for the slow speed service.

It has been too often the case that the ambitious desire of the

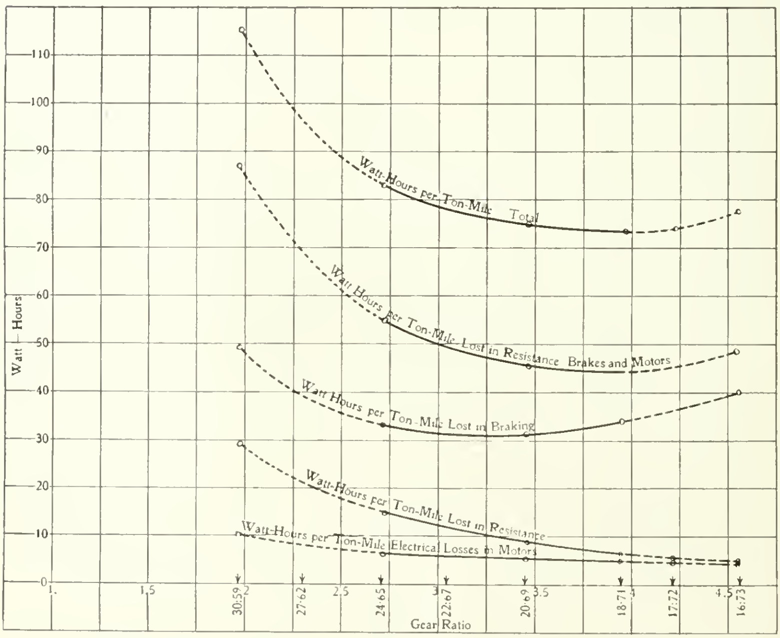


FIG. 3—PERFORMANCE CHARACTERISTICS OF 40 TON CAR WITH DIFFERENT GEAR RATIOS WITH A CONSTANT ACCELERATING CURRENT OF 138 AMPERES PER MOTOR

manager or engineer of the operating company for high speed blinds him to its cost, and the motors have been geared for a free running speed of 30, 40 or 50 miles per hour, when the maximum schedule speed on the line is 10, 15 or 20 miles per hour. This means that the motors will operate either in series or on resistance for a much larger proportion of the time than is necessary, and must perform their work at an average voltage considerably below normal. Hence

the working current and consequently the temperatures of the motors will be much higher than they should be.

In order to present this matter plainly, some curves have been prepared showing the results which may be expected by the application of different gear ratios to a certain motor equipment when operating on a given service. In the preparation of these curves the following conditions were assumed:—

Weight of car loaded	40 tons
Number of motors	4
Size of motors	75 horse-power
Line voltage	500 volts
Size of wheels	33 in.
Length of run	0.6 miles
Schedule speed	20 miles per hour
Length of stop	10 seconds
Rate of braking	1.5 miles per hour per second

It is assumed that the above conditions represent the most severe service to be encountered and that the operating company has

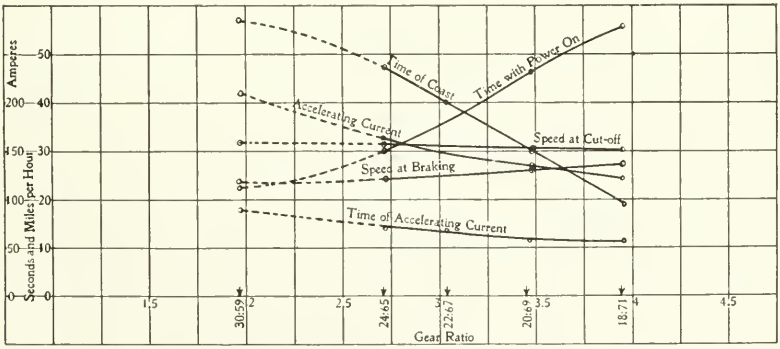


FIG. 4—PERFORMANCE CHARACTERISTICS OF 40 TON CAR WITH DIFFERENT GEAR RATIOS WITH A CONSTANT RATE OF ACCELERATION OF 1.5 MILES PER HOUR PER SECOND

purchased quadruple equipments of 75 horse-power motors. The question is, under the above conditions, what is the best gear ratio?

Two sets of curves, made up to meet the above conditions, are given; the first set is plotted with the same initial accelerating current for all gear ratios, and the second set shows the result of accelerating at the same initial rate with all gear ratios. For the sake of simplicity, the line is assumed to be a level tangent. Curves have been plotted for gear ratios ranging from 2:1 to 4.5:1. The time of run, including stop, is 108 seconds.

In Figs. 1, 2 and 3 are shown the results obtained with a constant accelerating current of 138 amperes, which is a fair value for a motor

of this capacity. Fig. 1 shows the time required to run with power on, time for coasting and the time for the maximum accelerating current; or, in other words, the time for running on resistance. The time for the maximum accelerating current varies from 37.5 seconds, with the 2:1 gear ratio, to 6.8 seconds with 4.5:1 gears. At the same time, the rate of acceleration varies from 0.8 miles per hour per second to 2.1 miles per hour per second.

Fig. 2 shows that the average voltage of the motor while power

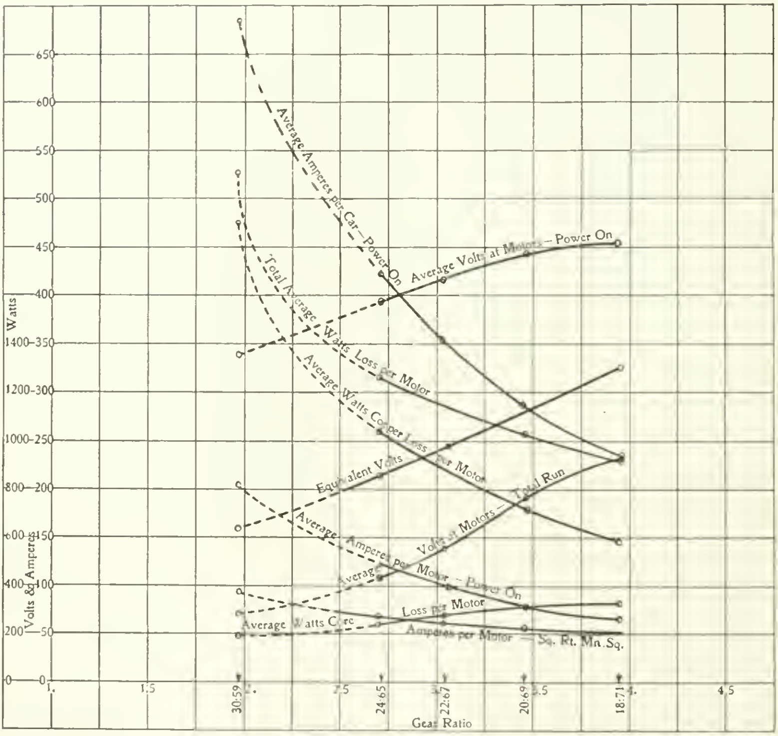


FIG. 5—PERFORMANCE CHARACTERISTICS OF 40 TON CAR WITH DIFFERENT GEAR RATIOS WITH A CONSTANT RATE OF ACCELERATION OF 1.5 MILES PER HOUR PER SECOND

is on is only 310 volts with 2:1 gears, while it rises to 480 volts with 4.5:1 gears. It is well known that motors are overloaded when the line voltage drops badly and this is just as true when the average voltage applied to the motor is lowered by changing the gear ratio. This fact will be more readily appreciated when it is seen that the average rate of taking current from the line is 130 amperes per

motor with the 2:1 gear and only 52 amperes with the 4.5:1. The average current *per car* under the same conditions is 430 amperes in the one case and 198 in the other. The square root of the mean square current per motor is 87 amperes for the 2:1 gear and 49 amperes for the 4.5:1 gear. The curves show average watts loss in the motor in copper and iron and the total electrical loss. They show that the *motor losses* will be a minimum with the maximum gear reduction. (It is recognized that the maximum gear reduction possible for this schedule would not be commercial as there is absolutely no margin for making the schedule, but it is shown simply to point out the fact that the greater the gear reduction for a given

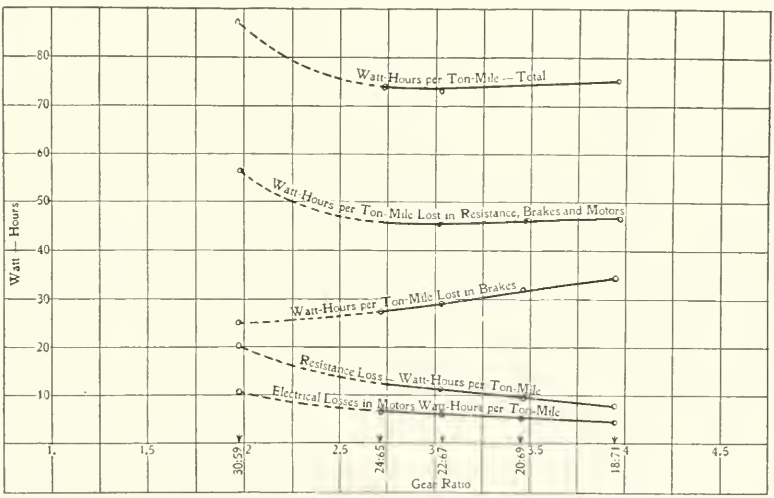


FIG. 6—PERFORMANCE CHARACTERISTICS OF 40 TON CAR WITH DIFFERENT GEAR RATIOS WITH A CONSTANT RATE OF ACCELERATION OF 1.5 MILES PER HOUR PER SECOND

schedule the lower will be the losses in the motor.) The curves in Fig. 3, however, show that the *power consumption* is a minimum at about the 4:1 gear reduction. The increase in watt-hours per ton-mile between 4:1 and 4.5:1 is coincident with and due to the increase in speed at the time the brakes are applied, as shown in Fig. 1. (See also Fig. 9.) The rise in watt-hours per ton mile with the 2:1 gear ratio is due to the increased loss in resistance and motors as well as in the brakes. The motor loss, it will be seen, is controlled almost entirely by the square root of the mean square current as the iron loss is small at all times and remains close to 300 and 350 watts for all gear ratios.

Figs. 4, 5 and 6 show the results obtained when accelerating at a constant rate of 1.5 miles per hour per second for all gear ratios. Fig. 4 corresponds to Fig. 1, Fig. 5 to Fig. 2 and Fig. 6 to Fig. 3. A comparison of these curves indicates that while a constant rate of acceleration produces a nearly constant power consumption per ton mile, the motors will be very much more overloaded with the lower gear ratios at the *constant rate of acceleration* than when accelerating at the *constant current*. This would be apparent only in commutation, since the total losses in the motor, *for any given gear ratio*, will be approximately the same, as seen in Figs. 2 and 5, regardless of the rate of acceleration. This is probably true only within narrow limits.

These curves have been plotted on the basis of the assumed

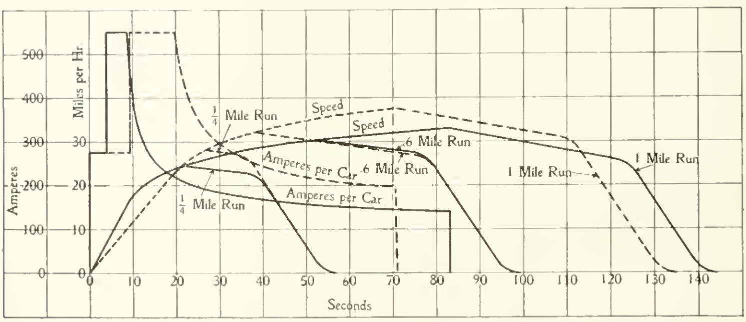


FIG. 7—SPEED-TIME AND AMPERE-TIME CURVES FOR THREE LENGTHS OF RUNS —CONSTANT ACCELERATING CURRENT PER MOTOR

Full lines—gear ratio, 18:71. Dash lines—gear ratio, 24:65.

typical run of six-tenths of a mile at a schedule speed of 20 miles per hour. In order to make comparisons between the different gear ratios with a longer run and with a shorter run, speed-time curves have been extended to correspond to the one mile run and the one-fourth mile run as shown in Fig. 7. The schedule speed assumed has been simply taken as the maximum which the lowest speed gear ratio could give with these lengths of run. These happen to be 13.6 miles per hour for the one-fourth mile run and 23.4 for the one mile run. These schedules could probably be maintained in regular service by the 18 to 71 gear ratio, as a moderate length of coast is given in each case and this speed could be forced still higher by a higher rate of acceleration and braking. It is understood, of course, that the conditions which were assumed were the most severe that would be found on a given service; that is, the loads were maxi-

mum and the number of stops also the maximum. This being the case, the 18 to 71 gear ratio or at most 20 to 69 gear ratio should do the work very satisfactorily. Table I shows that this gear ratio will meet the conditions with nearly a minimum motor heating and a minimum power consumption. If a higher speed is desired for the outlying parts of the system, it will be necessary to use a larger motor than 75 horse-power. For instance, if it were desired to use the 24:65 gear instead of the 18:71 the square root of the mean square current capacity per motor required would be increased from 51 to

TABLE I.

40-Ton Car, 4-75 horse-power Motors; Constant Accelerating Current of 138 Amperes; Stops, 10 Seconds; Braking Rate, 1.5 Miles Per Hour Per Second.

	Gear Ratio, 16:73.			Gear Ratio, 18:71.			Gear Ratio, 24:65.			Gear Ratio, 30:59.		
	1/4 Mile.	0.6 Mile.	1 Mile.	1/4 Mile.	0.6 Mile.	1 Mile.	1/4 Mile.	0.6 Mile.	1 Mile.	1/4 Mile.	0.6 Mile.	1 Mile.
Schedule Speed...	13.6	20	23.4	13.6	20	23.4	13.6	20	25	12.5	20	25.2
Amperes—Sq. Rt. of the Mn. Sq...	55.7	49	43.5	59.8	51	46.7	82.5	68	64.3	95.6	89	82.5
Acceleration.........	2.11	2.11	2.11	1.81	1.81	1.81	1.17	1.17	1.17	.807	.807	.807
Coast—Seconds....	4	3	6	15	22	40	7	37	38	5	25	38
Kw-Hrs. per Car Mile..........	4.4	3.08	2.61	3.98	2.95	2.36	6.15	3.3	2.98	7.67	4.65	3.68
Core Loss — Av. Watts..............	323	360	362	249	325	321	294	275	378	221	300	365
Copper Loss—Av Watts..............	663	510	417	768	600	484	1490	1035	912	2000	1720	1500
Total Losses—Av. Watts..............	986	860	779	1017	925	805	1784	1310	1290	2221	2020	1865
Watt-Hrs. per Ton Mile..........	110	77	65	99.5	74	59	154	82.5	74.5	192	116	92
Max. Sch. Speed—No Coast..........	13.6	20	23.4	13.95	20.4	24.15	13.65	20.8	25.9	12.7	20.6	26.3

68. The power consumption would be increased from 74 to 82.5 watt hours per ton mile, with no advantage except the ability to run at a slightly higher speed on a long run.

In studying these curves it will be well to bear in mind some general facts concerning the selection of motor equipment.

1—The only energy supplied to the electrical car equipment that may be termed useful is that required to overcome rolling friction and air resistance. The remainder of the power is expended in heating car wiring, resistance, motors, brake shoes and wheels. The

"useful" power is usually a relatively small portion of the total in ordinary street and interurban railway service. *The useful energy in watt-hours per ton mile may always be found by multiplying the train resistance in pounds per ton by two.* Thus if the train resistance is 15 pounds per ton, the useful energy will be thirty watt-hours per ton mile.

2—The loss of energy in braking is proportional to the square of the speed at the time the brakes are applied. Excluding the energy of the rotating parts and the train resistance, which will nearly balance each other while braking, the energy loss will be

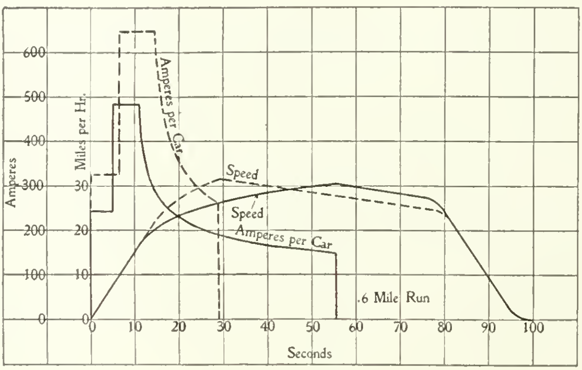


FIG. 8—SPEED-TIME AND AMPERE-TIME CURVES—CONSTANT ACCELERATION

Full lines—gear ratio, 18:71. Dash lines—gear ratio, 24:65.

approximately as shown in Fig. 9. This shows the watt-hours loss per ton per stop. The watt-hours per ton mile are obtained by multiplying the watt-hours loss per stop by the number of stops per mile. In this run of six-tenths of a mile the watt-hours per ton mile loss in braking will be equal to the useful energy (assuming a train resistance of 15 pounds per ton) if the brakes are applied at 27 miles per hour. Fig. 9 shows clearly the advantage of allowing a considerable length of coast after cutting off the power so as to apply the brakes at as low a speed as possible. It is extremely inefficient to apply the brakes immediately after the power is cut off and make a slow stop.

3—The loss in resistance where ordinary series-parallel control is used during one acceleration is approximately represented by the following formula:—

$$L = \frac{A\,V\,T}{3\,600\,W}$$

Where L=loss in watt-hours per ton, A=amperes per car with series position of controller, V=½ line volts—drop in motor, T= time of acceleration in seconds and W=weight of car in tons.

With a straight parallel control the loss in resistance will be almost one-half of the power used during acceleration up to the time resistance is cut out. The series-parallel controller cuts this down to about one-fourth. Thus if the proper accelerating current for a given size of motor is used, the resistance losses will be increased with a higher speed gear ratio especially in slow-speed city service. The loss in resistance is generally reduced by increasing the rate of acceleration for a given gear reduction.

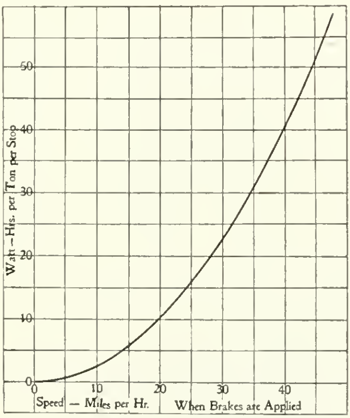


FIG. 9 — CURVE SHOWING WATT-HOURS PER TON PER STOP LOST WHEN BRAKES ARE APPLIED AT VARIOUS SPEEDS

The above comments on the curves which have been shown in this article do not cover the ground, they simply indicate some of the important points which should be given due consideration in coming to a decision as to the most desirable and economical arrangement of gears for any given service. To those who have not given the matter any particular thought, the preceding discussion will doubtless give a better appreciation of the importance of a correct selection of gears. It is hoped that the publication of these curves will lead to a much more careful study of the situation and that the demand for motor equipments geared for unnecessarily high speeds will be lessened thereby.

DOUBLE DECK TURBINE POWER PLANTS

THERE are now in operation three important examples of a new type of power plant known as the double-deck station.* This type of station embodies striking originality in its departure from long-established practice and in a most fortunate manner reserves for the steam turbine the benefits of certain advantages inherent to this high-speed prime mover. Attention has been called to the general features of these stations in papers by Mr. J. R. Bibbins, read before the last annual meetings of the American Street Railway Engineering Association and of the American Institute of Electrical Engineers. This type of station deserves careful consideration as it will doubtless be accepted as standard in many cases, especially for power plants of restricted area, as in cities, harbor frontages, hillside locations, etc. The following resume of the most characteristic features of the double deck station is based on the information contained in Mr. Bibbins' papers.

In spite of their relatively high speeds, turbine machinery is now built which may be placed on structural foundations with perfect safety, as there is an entire absence of cyclical movements due to unbalanced parts which require, in the case of slow-speed reciprocating engines, the most rigid foundations. For a number of years there has been a continual reduction in the bulk and cost of turbine units. In large sizes the floor area required by turbines has been reduced to about twenty percent of that required by modern vertical Corliss engines and to about ten percent of that for the horizontal-vertical type. Without generators, large vertical Corliss engines, including fly-wheels, weigh from 320 to 500 lbs. per kw, the weight increasing with the size, whereas large turbine units complete weigh about 15 to 20 percent of that amount, and the weight decreases with the size. With the horizontal type of turbine, foundation loadings may be distributed to permit of light foundation structures.

In the double-deck station a steel skeleton framework may be used to support not only the turbines, but also the cranes and roof trusses if desired, independent of the walls. By the use of steel

*The Spy Run Station of the Fort Wayne & Wabash Valley Traction Company; the West Point Station of the Youngstown & Ohio River Railroad and the Hamilton Station of the Cincinnati Traction Company.

supporting columns under the turbines and a continuous floor structure from wall to wall with pairs of plate girders extending across the building under each turbine bed plate, an exceedingly rigid structure is obtained. Short cross girders may be used to tie the longitudinal girders together at column intersections. Thus the weight of each turbo-generator set is distributed between two building walls and two rows of columns.

The proper relative arrangement of boilers and turbines in a double-deck station depends upon the size and capacity of boilers

FIG. I—SPY RUN STATION OF THE FORT WAYNE & WABASH VALLEY RAILWAY COMPANY

adopted. With boilers of small capacity there will be a larger turbine room above than is necessary, but with boiler units of large capacity a very compact arrangement is possible.

In discussing the relative arrangement of boiler and turbine capacity, three important factors are to be considered:—First, the number of units required; second, the boiler grate surface for the required rate of combustion, and third, the cost of supporting steel work for different spans. The first is fixed by the assumed station load, the second by standard boiler practice, and the third, the weight and cost of girders, increases with the span.

BOILER PLANT

A study of modern practice in the equipment of turbine stations shows a comparatively uniform proportion between boiler and generating capacity. Eighteen important turbine stations for railway and lighting service, which were considered, average close to one-half boiler horse-power per electric horse-power generating capacity including a considerable boiler reserve. In this connection it is well to remember that the greater the range of boiler capacity per unit the less the reserve necessary, the lower the investment in boiler plant and the less the space occupied.

Recent investigations and tests have revealed an important fact, viz., that the steam boiler is capable of absorbing heat with very nearly the same efficiency over a very great range of load.

The mechanical stoker has proven an exceptionally fortunate

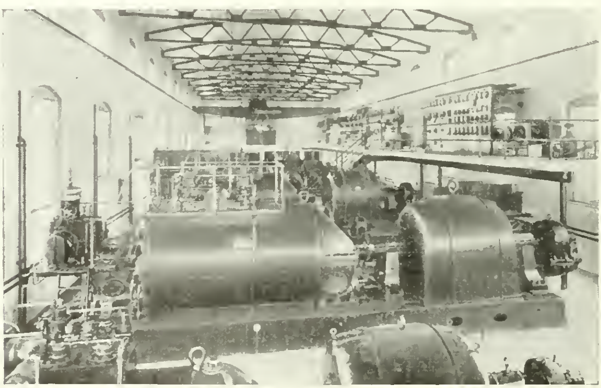


FIG. 2—TURBINE ROOM OF THE FORT WAYNE STATION

addition to power plant equipment as it insures a range of generating capacity far beyond the possibilities of hand firing. Present indications point to a combustion rate of from 20 to 25 lbs. per square foot per hour as a possible normal rate, whereas, this figure formerly stood some five pounds lower. In securing these higher rates of combustion the effective draft area of a furnace grate should increase with the rate of combustion. This is quite different from increasing the draft pressure alone with the rate of combustion, which is a fundamental weakness of the hand-fired flat grate. The problem is thus one of grate surface rather than heating surface.

Heretofore, in an endeavor to keep pace with the great increase in capacity of prime movers, the number of boilers per plant has

increased instead of the size of units, but to-day boiler units of 1 000 to 2 000 horse-power are in active demand. For large sizes hand firing is impracticable and in some cases the capacity of single stokers has been exceeded. For this reason the double-fired boiler has come into use. The double-deck station is particularly well fitted

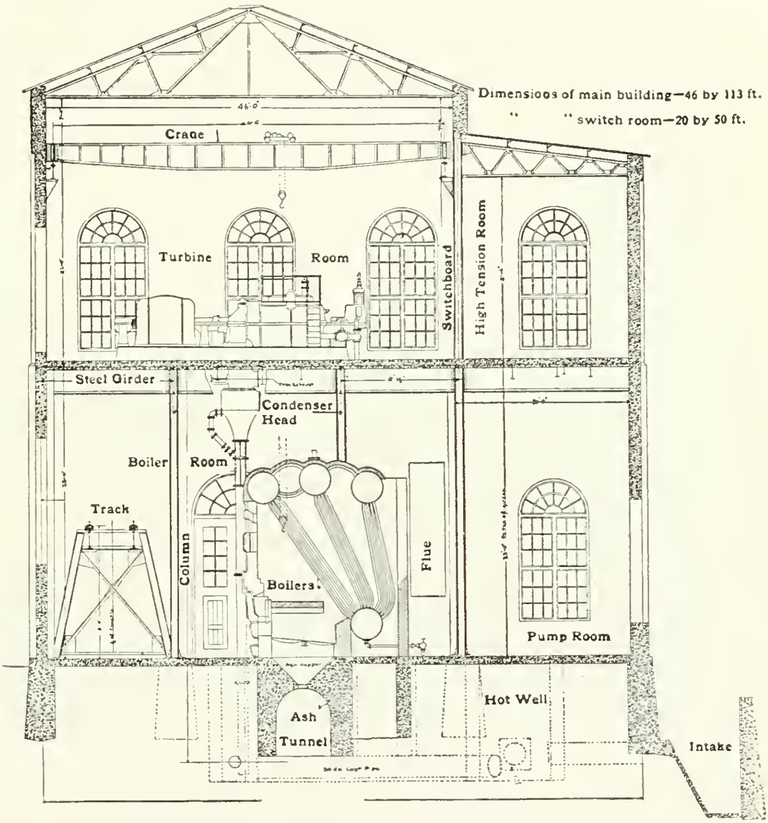


FIG. 3—SECTIONAL ELEVATION OF WEST POINT STATION

for this type of stoker as both ends of the boiler are accessible and external coal bunkers may be used.

STEAM PIPING

By placing the boilers directly underneath the turbines, the simplest and most direct form of steam piping may be used. Radiation may be reduced by the use of comparatively high steam velocities and small pipe sizes, without serious drop in pressure. On the unit system only two bends in the piping from boiler to turbine would be necessary. It is usually desirable, however, to have an equalizing

header running the length of the boilers, but this complicates the piping only to the extent of extra valves, fittings and hangers. By this method there is a very direct path for the steam from boilers to turbines and the equalizing connection can be used to compensate for any variation in the rate of steaming of the boilers in service and provide for convenient distribution of boiler capacity to carry any load. In the normal running of such a plant the boilers nearest the turbines in operation can be kept in service, thus giving a minimum distance of steam flow. When so desired, the station can be operated on the unit system by closing valves in the headers between the various risers.

CONDENSERS

The double-deck arrangement also permits of direct-connections from the turbines to the condensers. The height of the turbines above the ground level makes it possible to use jet or barometric condensers to good advantage. The barometric type fits particularly well into this scheme as the condenser head may be suspended directly beneath the turbine where its most bulky part is out of the way. The tail piece may then be carried down at any angle or turn necessary to clear obstructions. At the Fort Wayne station, twin condensers of one-half the size required are used instead of one large one. Thus in the event of the disablement of one condenser, operation may be continued with reduced vacuum with the other. At the West Point station there is a distance of only 2.5 feet from the turbine exhaust to the condenser head.

The degree of vacuum desirable appears to be a matter of opinion. For the majority of inland plants the high temperature of circulating water available during the summer months renders of no avail a condenser plant designed for a vacuum higher than 28 inches. The general preference seems to be for a moderate vacuum of 27 or 28 inches. In plants where there is a pressure or head of water available, the double-deck arrangement is extremely simple, as pumps may be avoided altogether. At the Fort Wayne station the lift is sixteen feet and long stroke reciprocating pumps are used. With this type of pump a small air chamber should be employed to carry over the moment of reversal without any "dip" in the vacuum. This equipment without dry vacuum pumps gives a vacuum of about 27 inches at full-load. At the West Point station high speed centrifugal pumps are used. These are more compact than the slow-speed reciprocating pumps and deliver a constant quantity of water.

GENERATING PLANT

The generating plant for the double-deck station is not materially different from that standard for other plants. At the Fort Wayne station both 25 and 60-cycle currents are generated. The generators are cooled by air from a steel ventilating duct which runs the full length of the building. By means of an auxiliary booster fan and suitable dampers, a large excess of air may be supplied to any machine which may be overloaded. The exciters are direct-connected to the generators, each having a capacity sufficient to furnish excitation for two generators.

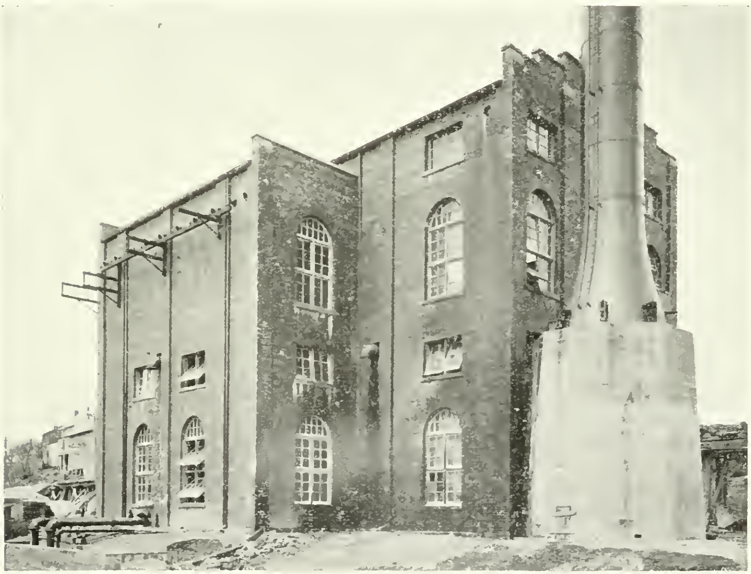


FIG. 4—VIEW OF WEST POINT STATION OF THE YOUNGSTOWN & OHIO RIVER RAILROAD SHOWING TWO STORY ADDITION

SWITCH ROOM AND AUXILIARIES

At the West Point station a 20 by 50 foot two-story addition at one side of the main building provides space for the switching and other electrical apparatus above, and the feed pumps, circulating pumps and other auxiliaries below. This makes an exceedingly convenient arrangement as it provides a rectangular engine and boiler room of minimum proportions with centralized auxiliary and electrical control apparatus, permitting installation of the switchboard in a most convenient position between the building columns, with all the

high tension apparatus in the rear, including circuit breakers and protective apparatus, with transmission line outlets near the roof.

SUMMARY

The features characteristic of stations of this type which have been built may be summarized as follows:—

1—Two-story rectangular brick structure with generating machinery above boilers on second floor; side wings for the accommodation of auxiliary apparatus, pumps, coal bunkers, etc.

2—Floor structure continuous from wall to wall, thus reinforcing entire structure.

3—Weight of generator apparatus supported entirely by steel building skeleton.

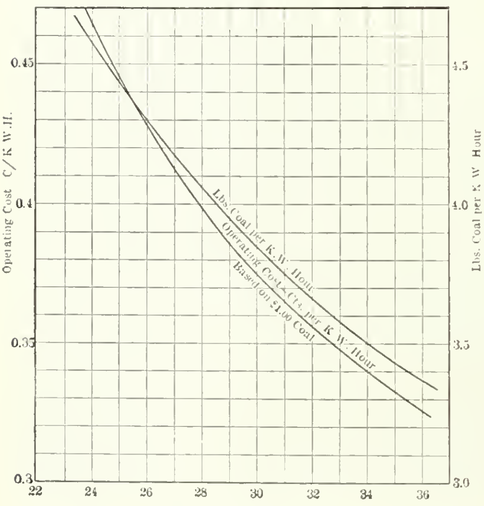


FIG. 5—EFFECT OF LOAD FACTOR ON OPERATING COST

4—Steam piping simple and direct with few bends, draining back from turbine throttle, high steam velocities and small size.

5—Steam header serves largely as equalizer, hence small in size; sectioned by valves; operates practically on unit system.

6—Steam header and supply lines controlled by pedestal extension valves from turbine floor.

7—Condensers hung from floor girders directly under turbine exhaust nozzles.

8—Mechanical stokers with gravity fuel feed, also mechanical coal and ash handling.

9—Two-story addition with operating switchboard located in division wall, leaving clear rectangular operating room and separate switchboard room, accommodating transformers, control and protective apparatus above, and heaters and auxiliaries below; also serves as transmission tower.

10—Generators air-cooled by positive blast piped from outside of the building to reach cooler air.

11—Crane reaches basement through removable sections of flooring.

COSTS

In the final analyses of the ultimate cost of power, fixed or capital costs, have an important bearing, and it is in this respect that the double-deck station deserves special consideration. In the preceding discussion, attention has been called to the engineering features of stations of this type. In the stations which have already been built, many of the refinements of modern power stations have been omitted, and hence a high operating efficiency can scarcely be expected. The eliminations of some of these refinements has, however, reduced the first cost. The general result has been to make the total cost of operation lower than in a more efficient plant with a higher investment.

Analysis of the total power costs of modern steam plants of 5 000 to 10 000 kw capacity show that the capital costs, including interest and depreciation, amount to about 50 percent of the total. For such high grade stations with thoroughly modern equipment, an investment cost of from $150 per kw in the smaller sizes down to $100 per kw in the larger, may be expected. In a very few large stations the equipment cost has been less than $100 per kw, but for stations under 10 000 capacity the cost is rarely below that figure.

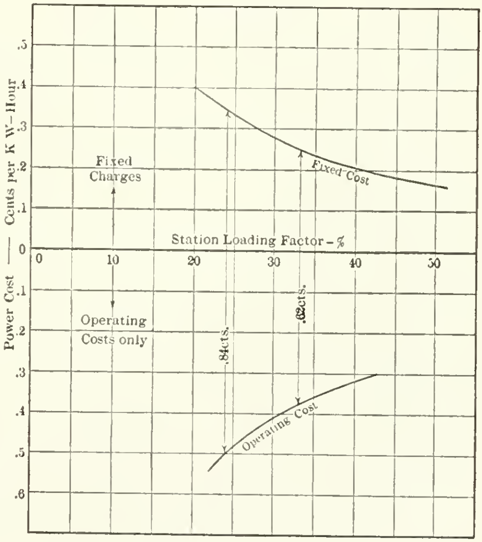


FIG. 6—VARIATION IN TOTAL COST OF POWER AT SWITCHBOARD WITH LOAD FACTOR (FORT WAYNE)

The cost figures for the Fort Wayne station are given in Table I. In this summary the building cost is naturally high, owing to the large amount of structural material necessary. On the other hand boiler and condenser costs are extremely low.

Using as a basis the above costs and the rate of variation with loading factor shown in Fig. 5, the ultimate total cost of power at different loading factors may be predicted, as shown in Fig. 6.

TABLE I.—COST OF COMPLETED POWER STATION, 8500 KW, NO SUB-STATION APPARATUS

	$	$ per kw.
Building: Including general concrete and steel work, coal bunker, smoke flue, condenser pit, coal storage pit, etc.	93,217	10.97
Boiler plant: Including boilers, superheaters, stokers, piping, pumps, heaters, settings, breechings, and tank..	118,313	13.92
Generating plant: Including turbines, generators, exciters, cables, switchboards, transformers, and ventilating ducts	259,711	30.55
Condenser plant: Including condensers, pumps, piping, free exhausts, water tunnels, and intake screen......	33,790	3.98
Coal handling plant: Including gantry crane, crusher motors and track	7,990	0.94
Erection, superintendence and engineering	50,500	5.94
Total, excluding property and siding	563,520	66.25

Fixed charges are dealt with entirely above the horizontal line and operating costs below. The total power cost at a given loading factor is then represented by the vertical distances between the two curves. The costs are based upon the following assumption:—

(a) Bond interest and taxes............... 7 percent
(b) Sinking fund equivalent to 6.43 percent depreciation* .... 4.2 percent
(c) Total fixed charges on capital cost.....11.2 percent

COMPARATIVE DATA

As extreme compactness is one of the striking features of the double-deck station, it is instructive to note its relative position in this regard to other turbine stations of both smaller and larger capacities. To this end Fig. 7 has been prepared, showing spaces occupied in the various stations. The lower curve represents net generating room area, exclusive of switchboard room, i. e., the actual

*Depreciation determined by summing the depreciation on the several parts of the plant, as follows: building, 3 percent; boiler plant and coal handling apparatus, 10 percent; condensing plant, 6 percent; generating plant, 7.5 percent; general average, 6.43 percent.

space devoted to generating machinery and the necessary auxiliaries. The second curve shows the relative ground floor area of the total plant as installed, whether single, double or triple deck. Here a great discrepancy appears, owing to the wide difference in arrangement of boiler rooms. In this respect, the comparative data serves hardly more than a record. Here the Fort Wayne station appears to the greatest advantage—showing the same relative compactness as stations some four or five times its capacity.

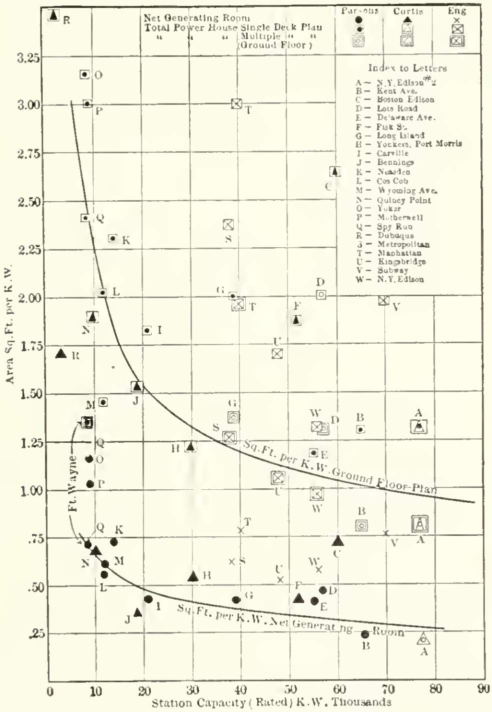


FIG. 7—CHART SHOWING RELATIVE SPACE OCCUPIED BY VARIOUS POWER PLANTS

Q=Spy Run Station of Fort Wayne & Wabash Valley Railway Company.

For purposes of comparison, a number of large engine-driven plants have been added to the diagram—Waterside Station, No. 2 appearing as the most compact notwithstanding the triple-deck boiler room of the Metropolitan Station.

From most standpoints, this type of station may be regarded as a distinct step forward in the field of electric power properties. Up to the present time no defects have appeared to occasion any fundamental change in plans and the stations may be regarded as eminently successful.

METER AND RELAY CONNECTIONS (Cont.)

APPARATUS FOR SYNCHRONIZING

HAROLD W. BROWN

SYNCHRONIZING devices are of two kinds; synchroscopes, which simply indicate the relative frequency and phase relations of two circuits, and automatic synchronizers, which automatically connect two machines or circuits in parallel when they are in synchronism.

SYNCHROSCOPES

The two kinds of synchroscopes here considered are similar in their indications, but somewhat different in principles of operation. One, the *magnetic vane* synchroscope, has stationary windings and a rotating vane, this vane being magnetized in phase with the e.m.f. of the incoming machine. Fig. 1 shows schematically the method of connecting the synchroscope, synchronizing lamps and transformers to the lines to be synchronized; the synchronizing plugs, switches, etc., are not shown. The upper terminals are connected to the incoming machine and the lower to the bus-bars, or to the running machine. The upper and lower left hand terminals are connected to the lines which are to come into phase with each other when the two circuits are synchronized; and similarly, the two right hand terminals are connected to the other sides of the same phase. Connections are made to synchronize simply one phase of polyphase circuits, as single-phase apparatus and connections are simpler than those required for two or three phases, and when once properly connected, the synchronizing can be done just as well in this way.

The other form of synchroscope known as the *motor* type is virtually an *alternating-current motor*, the stationary part of which is connected to one of the circuits to be synchronized, and the rotating part to the other. The leads for both circuits are brought out at the bottom of the synchroscope as shown in Fig. 2. The two coils A and B are seen to be connected to the same lines as the corresponding coils in Fig. 1. The magnetic vane synchroscope, being the one more commonly used, is shown in all the following diagrams. Any of these diagrams can be adapted for the motor type synchroscope by maintaining the proper relations as indicated above and shown in Figs. 1 and 2.

In addition to the synchroscope, it is customary to use a syn-

chronizing plug and synchronizing receptacles, and usually incandescent lamps and shunt transformers. The use of shunt transformers eliminates the danger to the operator of coming in contact with the high voltage of the generators, as one side of the synchronizing circuit is grounded as shown in Figs. 1 and 2. The synchronizing receptacles here referred to have six contact pieces, insulated from each other and arranged in two co-axial circles, three in each circle. Such a receptacle and plug are shown in Fig. 3. The two metal rings on the plug are insulated from each other, so that when the plug is pushed into the receptacle, each ring connects all the parts of one of the circles together, but the two circles are insulated from each other. The front circle of segments is connected to one of the lines to be synchronized, and the rear circle to the other. In some special cases, as explained later, the two rings are mounted on separate plugs, otherwise identical with the one shown, one plug con-

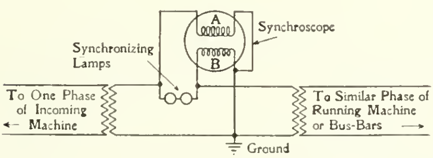


FIG. 1—CONNECTIONS OF MAGNETIC VANE TYPE SYNCHROSCOPE

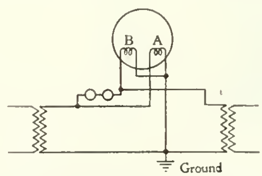


FIG. 2—CONNECTIONS OF MOTOR TYPE SYNCHROSCOPE, CORRESPONDING TO FIG. 1

These connections show schematically the arrangement of the synchroscope, lamp and synchronizing transformer circuits; the synchronizing circuit being grounded as shown, when the transformers are used. One lamp is placed on the generator panel and one near either the engine or the synchroscope. This arrangement serves to give a visible check both that the synchroscope is properly connected and that the right machine is being synchronized.

necting together the segments of only one circle. In this case connections are so arranged on the receptacle that the plug which short-circuits the front circle of segments connects to the incoming circuit, and the one which short-circuits the rear segments connects to the running circuit. Where a two-ring plug is used only one plug is required. In diagrams of receptacles it is customary to represent the circle of segments toward the front of the board by the three inner arcs, and the rear circle by the three outer arcs.

SYNCHRONIZING TO ONE SET OF BUS-BARS

A typical connection diagram showing the magnetic vane type of synchroscope is shown in Fig. 4. The connections for the motor

type are identical except as shown in Figs. 1 and 2. In either case, the right hand terminals of the two synchroscope coils are connected together. The other terminals of the synchroscope connect to a synchronizing receptacle for each machine (two are here shown); the synchroscope terminal for the incoming machine is shown connecting to the inner circle of each receptacle. From each receptacle, connection is made to the shunt transformer on the corresponding generator circuit. The synchroscope terminal for the running or bus-bar circuit connects to the outer circle of each receptacle and thence to the bus-bar transformer. Synchronizing lamps connect from the inner contacts of each receptacle to the running or bus-bar terminal of the synchroscope. One lamp is placed near the receptacle and indicates which machine is being synchronized, and the other lamp is in series with it near the synchroscope. The secondary e.m.f.'s of the transformers are approximately 110 volts, so that the voltage on the two lamps in series varies from zero to 220 volts, depending on the phase relation of the two circuits. With this connection the lamps are dark when the circuits are in phase with each other. The lamps are used to indicate the relative frequencies of the two circuits before the frequency of the incoming circuit has been made approximately the same as that of the bus-bars. As soon as the frequencies are nearly the same, the synchroscope indicates the phase relation much more accurately than do the lamps.

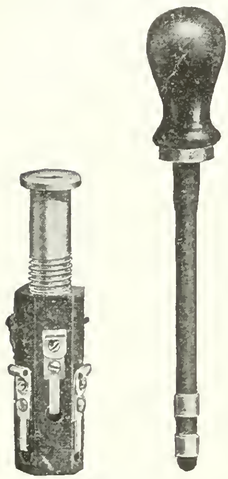


FIG. 3
RECEPTACLE AND PLUG

Connections Omitting Transformers—These connections are shown in Fig. 5, which is essentially similar to Fig. 4, but with the connections made directly to the line instead of through transformers. In this case, however, as the common connection would make one side of each

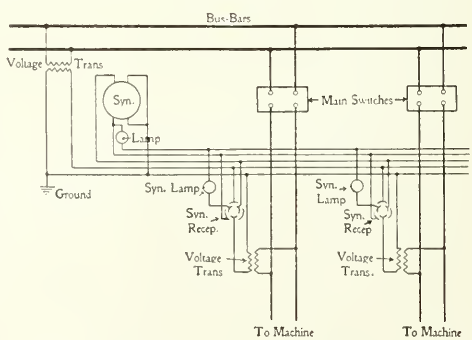


FIG. 4—CONNECTIONS FOR SYNCHRONIZING TO HIGH VOLTAGE BUS-BARS
Using the magnetic vane type synchroscope.

machine alive, even with the main switch open, it is made to the running machine through one ring of the receptacle. Also for the sake of line insulation the same reason the synchronizing circuit should not be grounded. Direct-connection is not suitable for voltages higher than 125 volts.

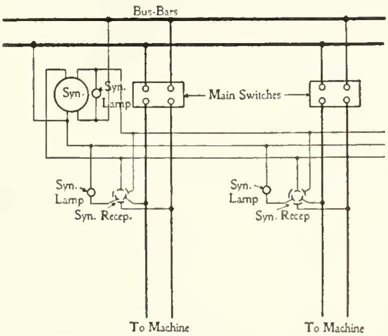


FIG. 5—CONNECTIONS FOR SYNCHRONIZING TO BUS-BARS WITHOUT TRANSFORMERS

Used on circuits of 125 volts or less

Auto-Transformers—The use of auto-transformers is illustrated in Fig. 6, which is otherwise similar to Figs. 4 and 5. One transformer is connected to the bus-bars, and a single auto-transformer is used with all of the machine circuits. This connection is used only on circuits of less than 500 volts, and even on these voltages it is not as often used as the regular tansformer connection, because, with the use of an auto-transformer, the synchronizing circuit is connected to the relatively high voltage of the line and must accordingly be insulated for this voltage, whereas, if the regular transformer connection is made, the synchronizing circuit is insulated from the line and grounded as shown in Figs. 1 and 2. A single transformer with a connection between the primary and the secondary could replace the auto-transformer, the connections otherwise being as shown here. With either one transformer or an auto-transformer the synchronizing lamps are both at the synchroscope and do not indicate which circuit is being synchronized.

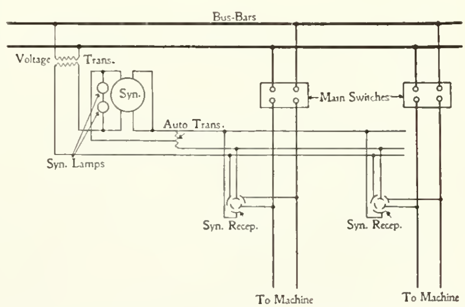


FIG. 6—CONNECTIONS FOR SYNCHRONIZING TO BUS-BARS WITH ONE TRANSFORMER AND ONE AUTO-TRANSFORMER

Used on circuits of less than 500 volts.

SYNCHRONIZING TO EITHER OF TWO SETS OF BUS-BARS

The connections for this case differ from the foregoing in that there are two synchronizing receptacles for each machine to be syn-

chronized. The connections of these two receptacles are identical except that one connects to the upper, and the other to the lower set of bus-bars. Fig. 7 shows the connections for high voltages. Similiar connections may be made without transformers or with an auto-transformer in the manner indicated for synchronizing to a single set of bus-bars.

SYNCHRONIZING AROUND SWITCHES

This is accomplished by connecting the inner contacts of the synchronizing receptacle to the incoming side of the switch and the outer contacts to the running side, which corresponds to the bus-bars. For high voltages, connections are made as indicated in Fig. 8. These connections may be modified for lower voltages, by omitting all transformers or replacing some of them by auto-transformers, as in the previous cases.

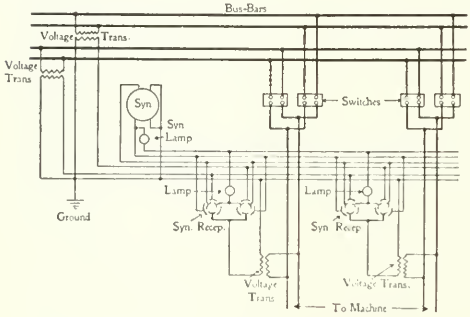


FIG. 7—CONNECTIONS FOR SYNCHRONIZING TO EITHER OF TWO SETS OF BUS-BARS

SYNCHRONIZING BETWEEN MACHINES

It is sometimes desirable to synchronize without connecting to the bus-bars. In this case, if any of the machines are running and another machine is being started, it is synchronized with one of the machines that is running. Where there are *only two* machines to be synchronized exclusively with each other, connections may be made as indicated in Fig. 9. With this arrangement, the left hand machine is connected to the inside of the left hand receptacle, and to the outside of the right hand receptacle; the right hand machine being connected to the inside of the right hand, and to the outside of the left hand receptacle. When the plug is inserted in the left hand receptacle, the left hand machine is connected to the incoming terminal and the right hand machine to the running terminal of the synchroscope. With the plug in the right hand receptacle, the right hand machine is connected for incoming.

Where there are *more than two* machines to be synchronized, connections are made as indicated in Fig. 10. The synchroscope is connected to the incoming and running circuits by means of two

special plugs such as have already been mentioned. As with other synchronizing connections, there is one receptacle for each machine to be synchronized. Both circles of contacts of each receptacle are connected to the machine to which the receptacle belongs. (In previous cases only one circle was connected to this machine, the other circle being connected to some other circuit.) The incoming terminal of the synchroscope is connected to the inner, (i. e., the front) circle and the running terminal to the outer (i. e., the rear) circle of each receptacle. The synchroscope is connected to the circuits by inserting a plug connecting a running machine to the running terminal of the synchroscope, and another plug connecting the incoming machine to the incoming terminal. With this method of synchronizing, care must be observed to insert the plug for the running machine (as shown in Fig. 10) *beyond the outer contacts* before inserting the plug for the incoming machine; otherwise a short-circuit will occur when the plug for the running machine comes in contact with the outer circle of contacts.

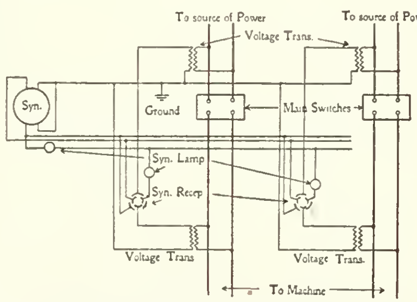


FIG. 8—CONNECTIONS FOR SYNCHRONIZING AROUND SWITCHES

AUTOMATIC SYNCHRONIZERS WITH ONE SET OF BUS-BARS

Automatic synchronizers have three circuits; one to be connected to a bus-bar transformer, one to be connected to a transformer on a machine circuit, and one making a contact in a direct-current control circuit when the other two circuits are in synchronism. Fig. 11 is a diagram of connections of an automatic synchronizer with the various auxiliary apparatus. In this diagram alternating-current circuits are designated by full lines; direct-current circuits operating the switches, by dash and dot lines and direct-current circuits lighting the indicating lamps, by dotted lines.

The equipment ordinarily used in connection with the automatic synchronizer includes the following:—a relay switch; a shunt transformer connected to the bus-bars, and additional apparatus for each machine consisting of a shunt transformer, an electrically-operated switch, a controller for this switch, and two indicating lamps. The

transformers used for meters, and the switches and controllers used for opening and closing the machine circuits may be used also for synchronizing, so that only a part of the apparatus required is used exclusively for synchronizing.

The electrically-operated switches have a closing coil, a tripping coil and a small double-pole, double-throw knife switch connected as shown at *S* in Fig. 11. This knife switch is mechanically-connected to the main switch so that, if the main switch is closed, the knife switch is automatically thrown to the right and if opened, the knife switch is thrown to the left. When it is thrown to the right it connects the tripping coil to one side of the direct-current control circuit. Two colored lamps at the controller indicate which way the switch is thrown, the red lamp indicating that the small switch is to the right and the main switch is closed, and the green lamp indicating that the main switch is open. These lamps may be omitted if desired as they are not essential to the working of the switch.

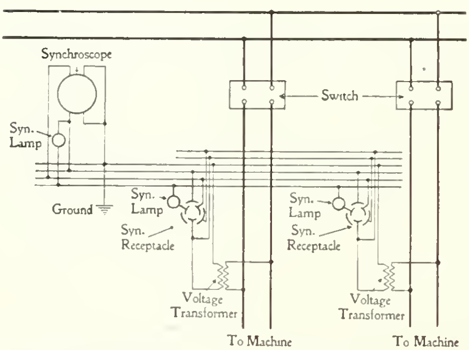


FIG. 9—CONNECTIONS FOR SYNCHRONIZING BETWEEN MACHINES WHERE TWO MACHINES, ONLY, ARE INVOLVED

The switch controllers have eight stationary contacts, indicated in the diagram, Fig. 11, by black circles, numbered from *1* to *8*. The black rectangles are the contact pieces on the moving drum. This drum is mounted with its axis horizontal, and the contacts are on the upper side of the drum.

At the top of the controller diagram is a finger contact marked *t*. The controller handle is hinged so that it may be lifted to a position perpendicular to the face of the switchboard. When brought to this position the finger contact is opened and the positive side of the direct-current circuit is thus opened. When, however, the controller handle is in the operating position, *t* is closed and connects one side of the control circuit to contact *7*. When the drum is turned to the right or left the rectangular contact pieces make electrical connection between certain of the stationary contacts. When the drum is turned to the right (i. e., the top to the right in the actual controller) and held there, contact *2* is connected to *1*; *3* to *4*, and *7* to *6* and *5*, thus connecting the bus-bar and machine trans-

formers to the automatic synchronizer and the control circuit to the closing coil and one of the contact terminals of the synchronizer. When the incoming machine is in synchronism with the bus-bars, the synchronizer makes its contact. With *t* closed, this sends a current through the winding of the relay switch closing its contact, this contact being heavy enough to carry a current much larger than that which the contact of the synchronizer could carry. The relay switch contact completes the circuit of the closing coil, and closes the switch connecting the incoming machine to the bus-bars.

When the controller drum is turned to the left, contact *2* is connected to *1*, and *7* is connected to *8*. This connects the bus-bar transformer to the synchronizer, and with *t* closed and *s* thrown to the right, it also closes the circuit through the tripping coil, which in turn opens the switch. When the bus-bar transformer is connected to the synchronizer, but the machine transformer is disconnected (as in the case just mentioned), the synchronizer is held away from its position of synchronism, so that the relay switch remains open, thus preventing a current in the closing coil when there is one in the tripping coil. Thus, when the controller is turned to the right, the switch is closed as soon as the machine is in synchronism with the bus-bars, and when it is turned to the left, the switch is opened. The controller handle is so arranged that, unless held at the synchronizing position, it will automatically return to the off position, whereas when turned to the tripping position it will remain there.

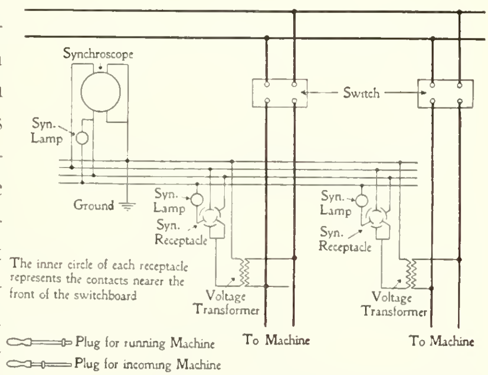


FIG. 10—CONNECTIONS FOR SYNCHRONIZING BETWEEN MACHINES WHERE MORE THAN TWO MACHINES ARE INVOLVED

WITH TWO SETS OF BUS-BARS

It is sometimes desirable to have connections to synchronize machines to either of two sets of bus-bars. Fig. 12 shows the automatic synchronizer with connections arranged for this. The connections are identical with those of Fig. 11, except that each machine has two switches and controllers, one connecting to the upper, and one to the lower set of bus-bars.

GENERAL*

It is customary to connect synchroscopes and automatic synchronizers as shown in these diagrams, which represent rear views; but there is no necessity for connecting them in exactly this way, inasmuch as the right and left hand connections may be reversed, except in case of the motor type synchroscope. Reversing connections on this instrument makes it indicate that the incoming machine is lagging when it is actually leading, and vice versa. With magnetic vane synchroscopes, the incoming machines connect to the top, and it makes no difference whether their respective receptacle and transformer connections are made to the right or left hand side, provided the right hand top terminal corresponds in

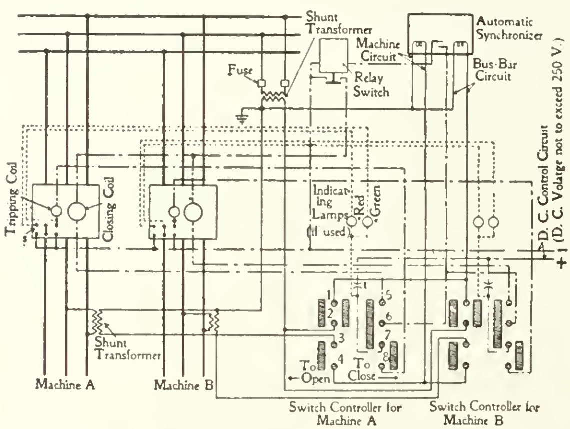


FIG. 11—AUTOMATIC SYNCHRONIZER CONNECTIONS FOR SYNCHRONIZING TO A SINGLE SET OF BUS-BARS

phase with the right hand bottom terminal connection, and the left hand top with the left hand bottom connection. Similarly with the automatic synchronizer, it makes no difference which is the machine and which the bus-bar circuit, but the right and left hand terminal connections of one must correspond in phase with the respective right and left hand connections of the other.

The machine to be synchronized may be a generator, a syn-

*There has been no attempt to consider either features of design, or operating conditions influencing the design, of the synchronizing apparatus referred to in this article. See the following articles which have appeared in previous issues of the JOURNAL: "Synchroscopes," by Paul MacGahan and H. W. Young, Vol. IV, p. 497, Sept., '07; "Mechanical Synchronizing," by H. S. Baker, Vol. III, p. 652, Nov., '06; "The Synchroscope," Vol. I, p. 692, Dec., '04; "Automatic Synchronizer," by Norman G. Meade, Vol. II, p. 294, May, '05.

chronous motor or a rotary converter, as the operation is the same, as far as the synchronizing apparatus is concerned. It is customary to ground the secondaries of shunt transformers used with meters and synchronizing apparatus; care should be taken, however, in case of a rotary converter where the direct-current circuit is grounded and where auto-transformers are employed. In this case the auto-transformer cannot be grounded, as with the two grounds a short-circuit would be made by inserting the plug in the receptacle. The same precaution, of course, applies to grounding any auto-transformer where, for any reason, it is necessary that the line be insulated from ground.

It will be seen by examining the diagrams of both the synchroscopes and the automatic synchronizers, that only two lines or bus-bars are required for synchronizing, and that there is no connection

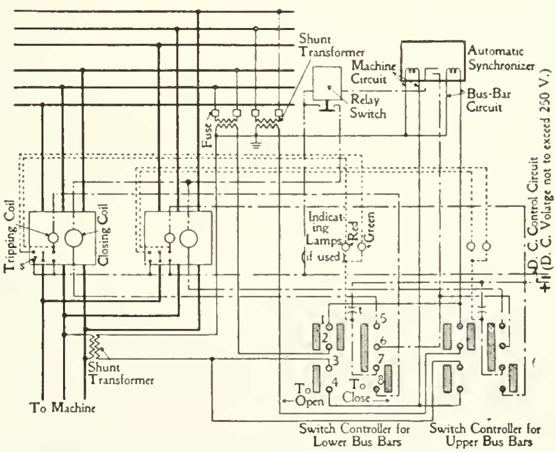


FIG. 12—AUTOMATIC SYNCHRONIZER CONNECTIONS FOR SYNCHRONIZING TO EITHER OF TWO SETS OF BUS-BARS

to any other phase. All synchronizing connections must be made in two-phase circuits across the same phase, and in case of three and six-phase circuits, between the same two lines. If transformers are used, one of the two lines is common to all the transformers of both the incoming and the running circuits, and this line is grounded and connected to the incoming and running terminals of the sychronizing apparatus. As has been noted above, it is customary to make this connection to the right hand terminal of each circuit of the synchroscope as seen from the rear. The left hand terminal of each circuit is then to be connected separately to the proper transformer through the synchronizing receptacle.

EXPERIENCE ON THE ROAD

DIRECT-CURRENT MOTOR TROUBLES

WILLIAM NESBIT

IN a certain shop the following arrangement was used for testing power chains. A ten horse-power, 110 volt motor received its current from a direct-connected generator, the engine also being belted to a line shaft. The motor was connected to the line shaft by a chain drive. By weakening the field of the motor its speed was increased so that it would return power through the chain drive. Any desired load on the chain under test was obtained by adjusting the field strength. After several years of successful operation in the above manner the motor unexpectedly became inoperative. Within a few minutes after starting it up and weakening its field to allow the current, corresponding to the torque required, to flow, it would be found that the current had for some unaccountable reason dropped to nearly zero and the motor would be simply running, without transmitting any power to the shafting through the chain drive. There was about one-eighth inch end play of the shaft and by pressing on one end of the shaft so as to stop the end motion, the current taken by the motor, and consequently its torque would raise immediately from zero to normal. In order to discover the cause of the difficulty the motor was then operated as a generator, receiving its power from the shafting through the chain drive and supplying current to a bank of lamps. With the shaft oscillating normally the voltage of the generator was 110 volts, but by preventing any end play, the voltage immediately rose to 115 volts.

The trouble was finally located in one of the field coils in the center of which a broken wire was found. When the shaft was not allowed to oscillate the ends of the broken wire were in contact and the motor operated properly, but when the shaft oscillated the vibration of the motor due to the pounding of the collar on the motor shaft against the bearing caused the ends of the wire to separate sufficiently to interrupt the field circuit. A new field coil cured this trouble.

TRANSFORMER TROUBLES

OPEN CIRCUITS

Several transformers were connected in parallel for feeding a secondary network. During the peak of the load one of these transformers burned out. The transformer seemed to be roasted from excessive overload and an inspection of the other two transformers in the group brought to light the fact that one of them was cold and had one of its high tension leads broken just under the terminal block, causing it to be open circuited. Although it had normal voltage impressed on its windings on account of its secondary connection to the network, yet it did not carry any of the lighting load at all, thereby overloading the other two transformers and causing the burnout referred to.

OIL TROUBLES

Burnouts sometimes occur due to the wiremen neglecting or forgetting to put any or sufficient oil in the transformer case. At other times the oil leaks out due to a faulty case, or excessive evaporation takes place after a long period of service, resulting in excessive temperature rise and finally in insulation breakdown.

WRONG CONNECTIONS

Transformers having series-parallel connections are sometimes so connected as to give double voltage on the windings. For instance, a transformer having a ratio of 2 000 or 1 100 volts primary to 110 or 55 volts secondary may be installed on a 2 200 volt circuit with the primary connected for 1 100 volts and the secondary connected for 55 volts. The transformers will give the desired 110 volts secondary, but since the windings are subjected to double the normal insulation strain and a large amount of the magnetizing currents would flow through the primary windings, insulation break-down will probably occur sooner or later and unless the connections have been carefully inspected the burnouts would probably be attributed to defective insulation.

Another wrong connection was a case where the transformer was connected up for 2 200 to 220 volts and 1 100 volts was impressed on its primary winding, giving 110 volts on the low tension winding. If such a transformer were loaded up, at 110 volts, to its rated capacity it would be liable to burn out as it would take double the current required at normal rating if properly connected.

In this case the transformer would be roasted out, whereas, in the above case, its insulation would break down.

A PECULIAR GROUND

R. W. CRYDER

After operating a 35 kw motor-generator set successfully for several days, it was discovered that when the conduits at the rear of the switchboard were disturbed, arcing occurred between them. It was immediately inferred that the motor, or the wires in the conduits connecting the motor to the switchboard, were grounded and that the arcing between the conduits was due to this ground. The motor operated on a 650-volt railway circuit, a tap running from the third rail to the positive circuit breaker on the switchboard, and a second one from the negative or ground rail, directly to a switch mounted on the frame of the motor. The wire connecting this switch to the negative rail was insulated, laid in loricated conduit and was probably seventy-five feet in length.

The motor and wires in the conduits were tested out and found to be free from grounds. Examination was then made of the wire connecting the negative switch to the ground rail and there it was discovered that the connection between the wire and rail had been removed. The negative line was thus broken but the circuit was by chance completed by a steam pipe which lay against the conduits and accordingly the motor continued to run. It is apparent that any disturbance to the conduits would cause arcing between them as the circuit was thus opened. The negative wire was again attached to the rail, the supposed ground removed and no more trouble was experienced.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

138—Resistance and Capacity of Dampers — What method is used for calculating the resistance and capacity of dampers used on the fields of railway motors? P. L.

A form of copper spool has been used serving the double purpose of a mounting for the field coil and a short-circuited damping coil, satisfactory results as regard its electrical performance being obtained when its construction is such as to give the necessary mechanical strength. As this device gives rise to objectionable features such as increased liability to flashing, due to its causing a sluggish action of the field iron, its use has been largely abandoned. S. M. K.

139—Division of Load Between Generators—A 500 kw steam turbo-generator operates a 500 kw, 600-volt rotary converter. When the rotary is paralleled with two 400 kw, 600-volt railway generators driven by Corliss engines it delivers twice as much current to the direct-current railway feeder system as the total power delivered by the two engine-driven generators. What can be done to distribute the load equally on the three machines? L. W. B.

At a total given load the distribution of load between three such machines will depend on the voltages of the three machines. These voltages in the case of the railway generators will depend on the field strength and the speed of the engines, and in the case of the rotary converter on the field strength of the rotary converter and the speed of the steam turbine. You do not give the percent regulation of the engines or of the turbine nor do you state whether shunts are provided for use in connection with the series fields of the respective machines, or at what percent of full-load this unequal division of load occurs. A definite recommendation, therefore, cannot be given. The following points should be noted, however: As the regulation of the steam turbine is ordinarily much closer than that of the reciprocating engine it is probable that as the load increases the voltage of the rotary converter is maintained at nearer a constant value than is that of the engine-driven generators. If the series fields are provided with adjustable shunts it may be found advisable to adjust the turbine governor to give a slower speed at full-load or at whatever load it is desired to obtain proper distribution of load. If this speed is too low it can then be compensated for on the rotary converter by decreasing the resistance of the series field shunt. It might thus be found possible with very slight adjustment of the governor and possibly an adjustment of the series field of the rotary converter to obtain just the desired characteristic performance curve to cause the machine to parallel with the railway generators throughout practically the full range of loads. In case shunts are provided for the railway generators it may be found possible to obtain the necessary compounding in the latter by either increasing the resistance or entirely eliminating it—depending, of course, upon the amount that the fields of the generators must be strengthened in order to cause them to take their proper share of the load. If this latter method of adjustment is applied the adjustment of the turbine governor need not be changed. C. F. L.

140—High-Tension Transformer Switching — Regarding the operation of high voltage step-down transformers, what is the best method of switching the transformers on or off? We formerly made a practice of closing the secondaries first and exciting from the low-tension side; now we close the primary first and excite from the high-tension side. It is claimed by some that closing the low-tension side first results in setting up a very high voltage on the primary side which is liable to break down the primary windings. The transformer in question is rated at 500 kw, 40 000/2 400 volts, and is oil cooled. I have noticed that, in the latter method of operation, in closing the secondaries first we sometimes get a very high current on our ammeter though this is not always the case. Kindly give the best method of operation together with your reasons for same; also explain the cause of the large ammeter reading. A. T. A.

In service there are three conditions under which the switching of transformers is likely to be demanded. First, the transformer may be gradually brought up to voltage when switched onto the line. Usually, when the station has been in service, voltage is on some of the lines all the time and it may not be practical to gradually bring the line up with the transformer. Therefore, it would be necessary to switch a live transformer on to a dead line unless the line may be energized some other way. Second, the ordinary switching of a live transformer on to a dead line as is usually found in the power-houses and some substations. Third, the switching of a live line on to a dead transformer, as is usually encountered at substations. The best way of doing the switching is, of course, to bring up line and transformer together. The next best way is to switch the transformer when live on to a line which is also live and at the same potential and phase position. The worst thing to do is the switching of a live transformer on to a dead line or a live line onto a dead transformer, each being about equally objectionable. Perhaps it may be a trifle worse to throw the live line on to the dead transformer, although the conditions may be just reversed under certain conditions. To summarize, it is necessary to provide transformers with sufficiently strong insulation to withstand any of the conditions of switching which have been described, but in order to limit the strains as much as possible, it is distinctly advisable to have choke coils arranged between the line and the transformer as surges which may come in from the line will in this way be interrupted and thus protect the windings of the transformer. It may be noted that the end windings of modern transformers are now always padded; that is, extra insulation is provided to withstand just such conditions. In Europe, provisions are sometimes made for switching transformers onto a live line through a series of resistances or reactances which are gradually cut out until the full voltage is impressed upon the tranformer terminals. This is an expensive and complicated process and does not seem to be warranted by American experience or practice. The complications of a 60 000 or 80 000 choke coil or resistance suitable for controlling the charging current of a transformer of similar voltage are obviously very considerable, beside the expense of the suitable switches and the protection necessary in operating them. It has been suggested that the switches and resistances, with which they are operated be put upon a low voltage basis through the medium of an insulating transformer. This may be warranted in some instances, though, of course, the decreased cost of the switches and resistances should be at least enough to pay for the cost of the insulating transformer. In this connection see article by Mr. J. S. Peck on "Current Rushes at Switching," also an editorial by Mr. Randall on "Transformer Switching," in the Journal for March, 1908. K. C. R.

141—Electrolytic Rectifier—What is the best method of connecting an electrolytic rectifier, and what are the current and voltage relations? E. R. S.

The best way to connect a single cell which will rectify both halves of the alternating-current cycle is shown in Fig. 141 (a). The choke coil offers a high impedance and prevents a flow of the alternating current. The intermittent direct-current, however, can flow out of the middle tap without serious drop because an equal amount comes

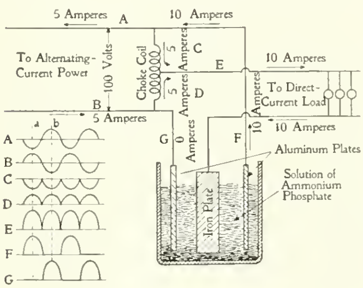


FIG. 141 (A)

from each end and goes around the choke coil core in opposite directions, thus giving no additional magnetization in the core. Current cannot enter the solution by an aluminum electrode, so the current coming through the alternating-current lead goes through one-half of the choke coil winding and enters the direct-current circuit through the middle tap. This current enters the cell through the iron electrode and returns through the aluminum plate on the other side of the alternating-current circuit. The choke coil with this current going through one-half of the winding acts like a one-to-one series transformer and if the current is to flow freely, there must be a secondary current in the other half of the winding which will be equal and opposite. This secondary current will flow through the direct-current circuit into the cell by the iron plate and out by the aluminum plate as before, but instead of leaving by the alternating-current lead, it completes its circuit through the other half of the windings. Thus there is, at any instant, twice as much current through the direct-current circuit as through the alternating-current circuit but at half voltage. The direct-current voltage if measured with a direct-current instrument which indicates average values will be the alternating-current voltage divided by 2.22 as the alternating-current voltage is necessarily the square root of the mean square reading. If both are read by alternating-current instruments (giving square root of mean square readings) the alternating-current voltage will be twice the direct-current voltage. The above gives the theoretical values of current and voltage but in practice these are not true on account of voltage drops and leakage in the cell, and on account of extra charging current for the choke coil and cell, and because the direct-current, instead of being a sine wave rectified, will be more or less smoothed out by inductance in the circuits. With each reversal of the alternating-current voltage the direction of current in the alternating-current leads is reversed and each aluminum plate alternates with the other in becoming active and then inactive. The instantaneous values and directions of current are indicated in the connection diagram Fig. 141 (a) for the instant that the current at *A* is flowing *from* the choke coil. The current waves in the various parts of the circuit are shown, the dotted line *a* indicating corresponding values of current in the parts of the circuit marked *A, B, C, D, E, F,* and *G*. Referring to the dotted line *b* the values of current are indicated for the instant that the current at *A* has a direction *toward* the choke coil. L. W. C.

142—Effect of Power-Factor on Temperature of Alternator—With an alternating-current generator of given k.v.a. output, do lower power-factors involve greater temperature rise in any part of the generator other than the field copper? C. I. Y.

Yes, the temperature of the armature of an alternating-current gener-

ator will increase as the power-factor is reduced, from two causes. First, the additional losses in the field will tend to increase the temperature of the air which cools the armature. Second, a higher electromotive force must be generated in the armature to secure a given terminal e.m.f. because the voltage drop through the armature is coming nearer and nearer in phase opposi-

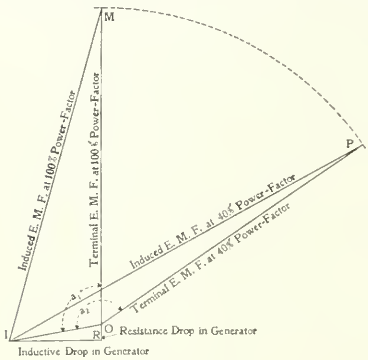


FIG. 142 (A)

tion to the e.m.f. at the generator terminals. This increases the iron losses. The relations of induced and terminal voltage and inductive, resistance and resultant drop are given in Fig. 142 (a) for the case of unity power-factor and also for a condition of low power-factor. As the power-factor decreases and the angle *a* increases the induced e.m.f. required to maintain a constant terminal voltage becomes greater.

143—CHARACTER OF INDUCTION MOTOR LOAD—Will a polyphase induction motor give a balanced load on a three-phase circuit? H. W. A.

Yes, unless the motor is very poorly designed or carelessly conconstructed. For example, if a uniform number of turns per coil is not used for the windings, unbalanced phases will result. Possibly you have in mind the effect observed with an induction motor operating on a power-factor less than 50 percent. If the power is being measured with two single-phase wattmeters, one of the meters will be observed to run in the reverse direction because of the low power-factor. A. M. D.

144—IRON LOSS IN RAILWAY MOTORS—Please describe and explain the methods used in making tests for iron losses in railway motors, for example, to obtain the iron loss curves shown in the article by Mr. Storer in the JOURNAL for July, 1908.

Tests for no-load core loss may be made in the same way as with shunt and compound-wound machines, and this is sometimes done. As the series motor is not a constant speed motor a number of runs at different speeds may be made. A method in which a separate driving motor is not required consists in putting a resistance in series with the field and connecting the armature across this resistance. The field current can be varied within the desired limits by changing this resistance, and the input to the armature will represent, approximately, the power necessary to overcome the friction, windage and iron loss of the motor at the respective speeds and corresponding field currents. The readings required are *speed*, *main current*, *armature current*, and *armature volts*. The friction losses are found separately by running the motor on a greatly reduced voltage across the armature, and a very weak field, preferably separately excited to insure steady conditions. The voltage is increased by steps to give speeds similar to those obtained in the combined core loss and friction tests. Running under these conditions, the strength of field, and accordingly the flux, is so small that the core loss may be neglected, and the input of the motor will give, approximately, the friction losses at the respective speeds. The readings required are *speed*, *armature volts*, and *armature current*. This latter test should be made both before and after the combined core loss and friction loss tests, an average of the results being taken and subtracted from the combined losses, the remainder being the core loss at the given speed and field excitation. Changes in friction, due to changes in temper-

ature, are thus taken into account. From the data thus obtained curves such as those referred to above may then be made. This test was explained by Mr. R. E. Workman in the article on "Factory Testing of Electrical Machinery" in the JOURNAL, Vol. I., p. 171. J. L.D.

145—ENAMELED WIRE—What is the nature of the material used in enameling wire such as that employed in the construction of small rheostats and fan motors? This material is apparently baked on the wire and serves as insulation. R. D. C.

Two general classes of material are employed for this purpose; a specially treated cellulose composition, very hard, yet flexible; and various drying oils, combined with a varying proportion of gums, designed to harden and strengthen the insulating film left after baking. R. D. D.

146—VOLTMETER COMPENSATOR FOR DROP—(a) When using a contact-making voltmeter for automatic voltage control on a four-wire, three-phase circuit in place of a line drop compensator, how is compensation for the drop in the neutral wire obtained when the circuit has an unbalanced load, without the use of a line drop compensator in the neutral? (b) A line drop compensator will compensate properly for the voltage drop due to ohmic and inductive resistances but the contact-making voltmeter has no adjustable arms for ohmic and inductive line constants. How can it compensate properly on any circuit which has a varying power-factor? (c) Is the principle of the contact-making voltmeter theoretically applicable for compensating line drop on the average single and three-phase, four-wire circuits? C. J. H.

It should be understood that the function of the contact-making voltmeter is merely to close an auxiliary circuit when the voltage across its terminals differs from a predetermined value. Aside from this, it has nothing whatever to do with compensating for line drop; this latter function is performed by a separate piece of apparatus used in connection with the contact-making voltmeter, called a "line drop compensator," such, for example, as is described in an article by Mr. Wm. Nesbit on "Voltmeter Compensation for Drop in Alternating-Current Feeder-Circuits" which appeared in the JOURNAL for January, 1908, p. 26. Connections between the compensator and the contact-making voltmeter are the same as though the latter were an ordinary indicating voltmeter. When performing its function in connection with a compensator, the contact-making voltneter controls the operation of the motor of a feeder type regulator, an auxiliary relay ordinarily being interposed to relieve the voltmeter contacts. P. M.

147—INCREASE IN IRON LOSS WITH TIME—What would be a reasonable percentage increase of iron loss for a 750 kw, 60-cycle induction generator operating at 166 r.p.m., which has been in constant service for ten years? L. P. P.

The iron loss in a generator armature consists of two elements—hysteresis loss and eddy current loss. The eddy current loss may again be divided into eddy currents within the laminations themselves, and eddy currents between laminations. The hysteresis element is affected by annealing and increases when the armature iron is subjected to temperatures of from 80 percent C. to 100 percent or higher. The amount of this ageing or increase in hysteresis loss, which is usually less than half of the total loss, varies greatly. The maximum ageing is reached in a shorter or longer period, depending on the running temperature of the machine. The lower the temperature, the longer the time required to reach maximum ageing. The total increase in this hysteresis loss depends also on the treatment which the steel receives before using. Proper annealing reduces the hysteresis loss to a minimum and also diminishes the total amount of age-

ing. The average increase in hysteresis loss under the average operating conditions, should not be more than 20 percent. Individual cases may vary from five percent to ten percent, depending on the material used and its treatment. The eddy current loss within the individual sheet depends upon its thickness and its ohmic resistance, and this loss is practically constant for all conditions of the material. The eddy current loss between the sheets depends upon insulation on the individual sheet and therefore varies as the insulation varies. When the iron is loose and there is serious vibration, the insulation of enamel or paper used on the sheets may be worn through, and a decided increase in the total losses result, due to the increased eddy current loss between the sheets. Such increase is not common, as there is usually little chance for the material once in place to be destroyed or lose its insulating property. It is impossible to give a satisfactory estimate as to the percentage increase in loss for the machine in question, as the kind of material, the tightness of the building, and the operating conditions are not known and, even if they were, actual measurement would be the only method of getting at this increase in loss, the loss at time of installation being accurately known. The general quality of material available ten years ago was far more variable than that obtainable at the present time, and this in itself would preclude any possibility of giving an exact estimation of the amount of ageing which may have occurred. C. E. S.

148—In the article on "The Analysis of Wave Forms" in the JOURNAL for July, 1908, p. 388, it is stated that $tan^{-1}\Theta_n = -\frac{A_n}{B_n}$. Please explain how the minus sign is derived. It is important in the discussion immediately succeeding this equation. F. F. S.

The matter of signs in the equation referred to is largely a matter of convention. The usual convention is to assume that upward directions are positive for one plane and that those from left to right are positive in the other plane. An inspection will show that, with the above conventions, when both A and B are of the same sign, the resulting angle between the point Y_0 and the nearest intersection of any harmonic with the base line is negative. If either of the above assumed conventions were changed the negative sign in the second member of the equation would be plus instead of minus, that is, if downward directions were called plus instead of upward for the one plane or if directions to the left were called positive instead of those to the right for the other plane. If both of these conventions were reversed, the minus sign would remain as indicated.

P. M. L.

149—In the article on "Wave Form Analysis" by Mr. Lincoln, in the JOURNAL for July, is there not a typographical error in the use of $tan^{-1}\Theta$ instead of $tan\,\Theta$ in formulas (*3*) and (*7*) on pp. 388 and 390 respectively? Also in Mr. Kintner's editorial there appears the error, "If A is minus and B is plus, the harmonic crosses to the *left* going upward." This should read *"right."* R. M. F.

As noted in your criticism, there is a misprint in the use of the word *"left"* instead of *"right"* in the fourth statement on page 362 regarding the relative position of the point at which the harmonic crosses the line representing the zero value. Regarding equations (*3*) and (*7*), the expression may be read: "* * the following relation will exist, the inverse tangent equals minus the quantity An divided by Bn." Your criticism, however, is a good one, as it would have been better to omit the sign of the inverse tangent, the expression in (*3*) then reading: "* * the following relations will exist, the tangent of the angle $_n$ equals minus the quantity A_n divided by B_n." S. M. K.

THE

Electric Journal

Vol. V. OCTOBER, 1908 No. 10

Large High Speed Turbo-Generators

Mr. Ehrhart states, in his article on the "Development of the Double Flow Steam Turbine," that one reason for the development of turbines of the double flow design is the "Development along electrical lines, enabling generators of high power to be operated at speeds hitherto not considered." With equal truth it may be said that the development of high speed turbo-generators of large capacity has been due to the requirements of the steam turbine. These two developments, namely, of the generator and of the turbine, have not been carried on independently, for there has been no demand for such excessively high speed generators except in connection with steam turbines. From a commercial standpoint the latter may be considered as an inherently high speed machine. The electric generator practically, although not inherently, has been considered as a relatively low speed machine. When it came to connecting the two together in one unit it was necessary to make some compromise in both, and in consequence the turbine has been operated below its most suitable speed, in many instances, while the generator was built for the highest speeds considered feasible at the time. In consequence, subsequent development was naturally in the direction of higher speeds and as there was a field for higher speed generators the skill of the designers was turned in that direction. The problem has been largely a mechanical one and almost all companies manufacturing such machines have worked along different lines of construction. This applies particularly to the rotors of alternating-current turbo-generators. Certain types of rotors have proved very successful up to certain limiting speeds, but still higher speeds being desired, such constructions had to be abandoned in favor of others. In consequence some of the differences between the rotors of various types of turbo-alternator furnished by American and European companies may be accounted for by the speed conditions adopted by the different companies.

When a suitable high speed mechanical construction is obtained, astonishing results can be secured compared with what was considered feasible a very few years ago. Mr. Ehrhart speaks of 10 000 kilowatt two-pole machines to operate at 1 500 r.p.m., and such machines are under construction at present, and with the mechanical construction of rotor adopted in these machines it may be possible to go to still higher outputs, possibly to 15 000 kilowatts.

One of the points in the above statement which will appeal to designers of alternating-current machines is the fact that these enormous outputs are obtained with machines having only two poles. In ordinary alternator practice the number of poles is usually increased for larger outputs, and only a short time ago it would have been considered impracticable, from the engineering standpoint, to make a satisfactory 10 000 or even 6 000 kilowatt, two-pole alternator. Such machines in their electric and magnetic design obviously require proportions radically different from those in lower speed machines. Theory indicates that such machines are feasible and the practical success obtained verifies the accuracy of the theory. One very noticeable feature in such machines is the extremely large air-gap. The depth of gap used must seem very wasteful to the ordinary observer; but, in fact, such gaps are very necessary in such machines. To secure suitable regulation characteristics the magneto-motive force of the fields must considerably exceed that of the armature and will be relatively great per pole. Only a small part of this can be expended in magnetizing the field and armature cores and the remainder must be expended in magnetizing the air-gap. This is cited merely as one of the unusual features in machines of this type.

For high speed 60 cycle generators it appears that a speed of 1 200 revolutions will be used eventually for capacities corresponding to the above 25 cycle machines. This speed requires a six-pole field structure and the constructive features necessarily will be different from those of the two-pole, 1 500 revolution machine. In fact, it may be said that for such speeds the two frequencies present two radically different problems to the generator designer and, as far as the demand has arisen, he has solved both.

B. G. Lamme

Single-Phase Electric Railways

The articles on "The St. Clair Tunnel Electrification" and "The St. Clair Tunnel Single-Phase Locomotives" in this issue, describe one of the recent and important electric railway installations. This installation is of especial interest as it employs the single-phase system for heavy trunk line locomotive service for both passenger and freight traffic. In this case, where the electrified zone includes only the tunnel and approaches, certain special conditions and difficulties exist. These have been met and overcome by the change from steam to electric locomotives. The first tunnel electrification was that of the Baltimore & Ohio Railroad at Baltimore in 1894. At present there are a number of other main line tunnel electrifications, involving heavy locomotive service, in operation or in course of construction in this country, as follows: The New York Central & Hudson River Railroad at New York; the Grand Trunk Railroad at Port Huron; the Lake Shore & Michigan Southern Railroad at Detroit; the Pennsylvania Railroad at New York; the Great Northern Railroad at Cascade Tunnel. Abroad there are the Metropolitan Underground System, Finchley Road—Baker Street section, London; the Simplon Tunnel, Italy and Switzerland, and the Imperial Government Railway, Japan, is now under consideration.

For successful commercial operation on a large scale, the first and most important consideration is in reference to the distribution system and the collection of current for the motors, it having been found from experience that simplicity, safety, flexibility and reduction to a minimum of all current carrying conductors are highly desirable. In heavy traction work, aside from the initial investment, the matter of safety to the public is not only important but in many cases controlling, especially in this country, where grade crossings exist and the right-of-way is such in name only. Some reliable form of overhead distribution is the logical solution of the problem. Both the single-phase and three-phase traction systems employ this form of construction. With two trolley wires, as required with the three-phase system, there is a maximum safe potential limit of about 3 000 volts, due to the difficulty and danger incident to collecting current at high voltages from two conductors. If a catenary form of construction is employed, similar to that used in single-phase work, the distributing system becomes so complicated as to be practically pro-

hibitive. Even in the simplest form there is much difficulty and complication. The moderate voltage allowable with the three-phase distribution system does not permit an electrical lay-out at all comparable with that possible by the use of the single-phase system at much higher potentials.

Second in importance in heavy traction work is the design of the motors and control. It is desirable in many cases to employ multiple-unit operation. On account of their speed characteristics it is necessary for three-phase motors to operate at the same speed, providing the load is to be divided properly between the motors. As the wheels of locomotives wear unequally, it is apparent that to secure satisfactory multiple-unit operation it may become necessary to adopt some such remedy as the insertion of resistance in the circuits of the motors having the largest wheels, thereby reducing the motor efficiency. The speed characteristics of single-phase motors are such that a similar contingency never exists. With single-phase motors multiple operation may be accomplished simply and efficiently as the motors are of the variable speed type in contrast to the constant speed three-phase motors.

Where a railroad is to make a change from steam to electric power, it is often desirable, where grades exist, to consider regeneration or electric braking. Both the three-phase and the single-phase system can employ this method of returning power to the line. With three-phase motors this is accomplished automatically at a slight increase above synchronous speed. Any other speed than the synchronous speed must necessarily be obtained by the use of resistances in the motor secondaries. With single-phase motors regeneration may be effected at a number of running speeds, and it is possible for a locomotive to control any load on a down grade which it can haul up the grade.

It would appear advantageous, also, to call attention to the matter of horse-power rating of locomotives. Not only is it possible with an equal motor temperature rise to perform a given run with a single-phase locomotive having a lower nominal horse-power rating than the required three-phase locomotive, but also the power consumption will be less in spite of the higher efficiency of three-phase motors. Also such motors must accelerate with much heavier currents to get the same tractive effort, since the field strengths of three-phase motors remain the same as when operating at the maximum speed, the torque being proportional to the product of field strength and armature current.

The single-phase system of electric railway operation has now been in use for over three years. While it is natural to consider the work accomplished in America during this time, it is also important to investigate the advances which have taken place abroad. The table of single-phase roads given in this issue shows that there are at the present time a number of such roads in successful commercial operation abroad. A table was published in the February issue containing data on the single-phase roads in America, from which the following summary was obtained: Total number of roads, 28; mileage in operation, 691.8; mileage under construction, 274.5; or a total of 966.3 miles; total number of cars, 240; total number of locomotives, 57; total motor horse-power, 137 400.

The foreign single-phase roads may likewise be summarized as follows: Total number of roads, 36; mileage in operation, 771.05; mileage under construction, 57.75; or a total of 828.8 miles total number of cars, 222; total number of locomotives, 43; total motor horse-power, 64 160.

It will thus be seen that there are in this country and abroad single-phase roads as follows: Total number of roads, 64; total miles of road, 1795.1; total number of cars, 462; total number of locomotives, 100; total motor horse-power, 201 560.

The rapid growth in single-phase railway operation the world over during the past few years cannot fail to be appreciated from the foregoing final summary.

J. Edgar Miller

THE ST. CLAIR TUNNEL ELECTRIFICATION

H. L. KIRKER

INCREASE in capacity was the primary object of the electrification of the St. Clair Tunnel. Steam locomotives could scarcely clear the summit of the grade leading out of the tunnel with a seven hundred ton train. The single-phase electric locomotives can take a thousand ton train up the two percent grade at ten miles per hour. They have solved the tunnel ventilation problem and removed a serious handicap to the passenger service. They have also improved the service in other respects,—for instance, the air brakes can now be used on freight trains in the tunnel. Under steam conditions the use of air brakes on freight trains was such a dangerous matter that hand brakes only were used except on the locomotive. The use of air brakes meant that when a train broke in two on the grade in the tunnel a portion of the train oscillated back and forth several times before it could be brought to rest with the hand brakes. The danger from the air brakes was due to the fact that the time required to recouple the train and release the brakes exceeded the time the steam locomotive could be kept in the tunnel with safety. Releasing by hand was a tedious and consequently hazardous operation. With the electric service the breaking of the train line immediately applies the air brakes to the whole train, and should a derailment occur the electric locomotive can be kept in the tunnel with safety as long as necessary. The electric locomotives have proved to be less severe on the rails than the steam engines. The depreciation of the passenger coaches, due to the effect of steam and hot gases on coming into the tunnel, has been eliminated. There has been a reduction in the coal bill, but more time will have to elapse before a fair comparison can be established between the cost of the steam service and the cost of the electric service.

A formal inauguration of the new service has not as yet taken place, notwithstanding the fact that electric service has been in full operation since May 17th, 1908; in fact, the great bulk of the traffic was hauled by the electric locomotives for two months prior to this date, during which time they handled the entire tunnel service for eighteen hours out of each twenty-four. This eighteen hour schedule was instituted after a month of preliminary intermittent operation. The electric service has been carried on from the start by the

same crews that operated the steam trains. The rapidity and success with which the steam locomotives have been eliminated from the tunnel is a testimonial to the adaptability of the steam men to electric service and to the fitness of single-phase locomotives for heavy grade work. It takes at least four years to develop a steam locomotive engineer. It took less than three months for the locomotive engineers to acquire a working knowledge of the electric locomotive. In this connection it should be stated that since it took from twenty to thirty minutes for the insulators to dry off after a steam train passed through the tunnel, a mixed service was impracticable. During the transition period the locomotive crews operated both the steam locomotives and the electric. This method resulted in an easy familiarity with the new equipment, since experience was

SINGLE-PHASE LOCOMOTIVE HAULING LONG FREIGHT TRAIN UP GRADE FROM THE TUNNEL UNDER THE ST. CLAIR RIVER

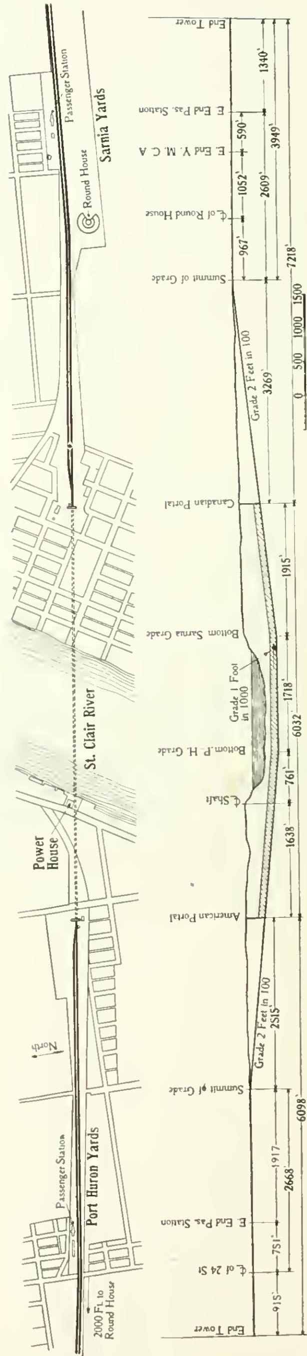
acquired in installments. The periodic reversion to the steam locomotives relieved the strain incident to the running of the new locomotives. The knowledge that the steam locomotives were available was mainly accountable for the confidence with which the men took hold of the new work. The eighteen hour service was carried on so smoothly that continuous service was instituted and carried on without apparent effort.

In general the electric locomotives have quietly eliminated the steam locomotives and taken up the work without any disturbance to traffic. With the electric service in full operation the tunnel is no longer the limit to traffic, since its capacity now exceeds that of the terminal yards.

THE TUNNEL

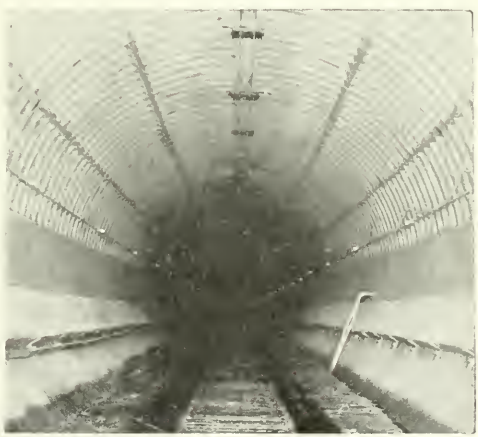
Electrification was the logical solution of the conditions at the St. Clair Tunnel, namely,—heavy service, heavy grades and bad ventilation. The St. Clair River is deep at Port Huron. The level portion of the tunnel is one hundred feet below the level of the yards, hence the mile of two percent grade required to reach the surface on either side of the river. The distance from summit to summit is approximately two and a quarter miles, although only six thousand and thirty-two feet of this distance is tunnel, as approximately a half mile of each approach is an open cut. The level portion of the tunnel connecting the two grades is a third of a mile long. These conditions mean that with steam service natural ventilation is practically impossible. Various attempts were made at artificial ventilation, but none of them proved successful.

The double track on the grades merges into a single track just outside the portals. The shell of the tunnel is twenty feet in diameter and is made up of cast iron rings composed of thirteen segments eighteen inches wide. There are therefore some four thousand of the bolted rings in the tunnel shell. The construction is solid and well jointed, consequently practically water tight.



MAP AND PROFILE, ST. CLAIR TUNNEL ELECTRIFICATION

Steam service was inaugurated in 1890, prior to which time the connecting link between the American and Canadian Grand Trunk Railway system was a car ferry. The tunnel division was necessarily the most important one in the whole system as traffic had increased until the steam locomotives were no longer able to handle all the business during the busy seasons, as for instance, when lake shipping was closed. Heavy engines built especially for the tunnel service were used to haul the trains through the tunnel. They burned hard coal. This avoided smoke, but of course did not eliminate the gases of combustion nor the exhaust steam, consequently there was always one element of danger in the atmospheric conditions resulting from the rapid succession of trains in alternate directions. The time required to traverse the tunnel was about four minutes. The trip was uncomfortable but, if continuous, was not necessarily dangerous. However, any accident that held a locomotive in the tunnel meant that the danger limit had been reached. Fortunately no such accident has ever occurred with a passenger train, but they have occurred with freight trains. The tragic results of some of these derailments and break-in-twos gave the tunnel a sinister reputation, which reputation electrification has removed The tunnel air is now as pure as the lake air and is always cool. The tunnel shell has been cleaned and whitened. Incandescent lights have been installed, and now instead of the former conditions of steam and fumes the tunnel is a clean, well lighted gallery.



INTERIOR VIEW OF TUNNEL

POWER STATION

The power station is situated on the Port Huron bank of the St. Clair River, at a point almost directly over the tunnel. The building construction is of concrete to the dynamo room floor. The walls above this point are lined with paving block and are corniced

and coped with concrete. The roof is of cinder concrete. The dynamo room is lofty and well lighted. The walls are lined with enamel brick to the height of the switchboard, the remaining portion is lined with sand lime brick. The offices and switchboard room occupy the street front. The basement has plenty of head room and contains the condenser pump groups and stoker fan groups. The dynamo room floor is so recessed that the auxiliary apparatus in the basement is in view from the dynamo room floor. The boiler room floor is on the same level as the dynamo room basement floor.

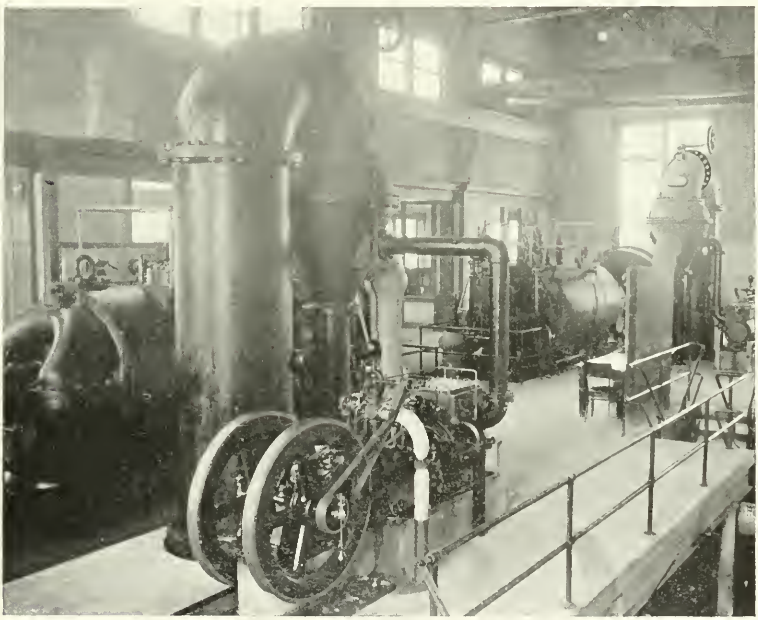
POWER HOUSE OF ST. CLAIR TUNNEL COMPANY AT PORT HURON

The striking feature of the boiler room is the reinforced concrete coal bunker. This extends the entire length of the boiler room, and has a capacity of 500 tons.

The power station equipment is in duplicate. There are two 1 250 kw, three-phase, 25-cycle, 3 300-volt turbo-generators. Either of these is capable of handling the maximum demand upon the station. Each turbine has its independent barometric condenser. There are two steam driven exciters and in addition a motor driven exciter group. The momentary peak loads have reached 2 400 kw, single-phase. A Tirrill regulator keeps the voltage of the locomotive phase uniform over the entire range of load. There is in addition

to the locomotive load a small three-phase load consisting of power house motors, drainage pump motors and round house motors. The incandescent lighting is connected to same phase as the locomotives.

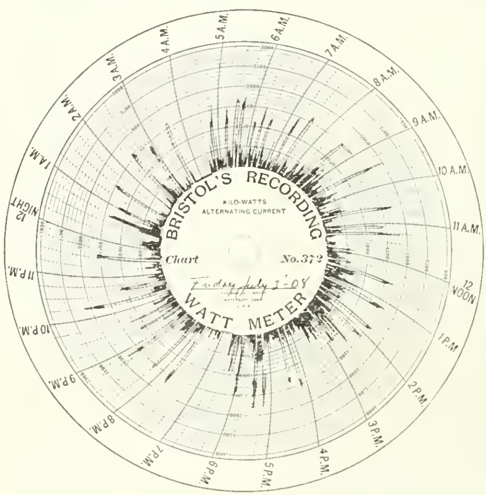
Since there is but a single track in the tunnel, there can be only one train on the grade at a time, consequently the load is an extremely variable one. The plant has been designed to meet these conditions. The turbines have a large overload capacity and the boilers have extra large steam drum capacity. The four boilers have a nominal rating of 400 hp each, and each boiler has three steam drums. Ordinarily there are three boilers in use, although



VIEW OF INTERIOR OF POWER HOUSE SHOWING TURBINES, CONDENSERS, ETC.

two are sufficient to care for the average load. Steam is kept up in the third boiler in order to avoid the delay which would occur in getting it into commission in case of an accident to an active boiler. When there is a drop in boiler pressure due to a heavy overload the speed of the forced draft fan engine is automatically increased, and at the same time the fuel supply to the underfeed stokers is automatically increased by the speeding up of the stoker feeding mechanism. The nominal boiler pressure is 200 pounds and the nominal turbine pressure is 175 pounds, consequently some drop in steam

pressure is allowable, but the automatic action of the stokers is such as to keep the drop from becoming excessive. The separately fired superheater is of a type that has considerable heat storage capacity. Each tube is surrounded by cast iron gills and contains an inner plugged tube whose diameter is so near that of the tube proper that practically all of the steam comes in contact with the heating surface. The temperature is controlled by the means of dampers, which are automatically operated by a water piston whose valves are operated by an electro-magnet primarily controlled by a thermo-couple in the steam line. The automatic control is arranged for a low uniform superheat in order that there may be no wide variation of temperature in the exhaust portion of the turbine when a heavy change in load occurs. High pressure superheated steam is used in the turbine alone. An auxiliary steam line, tapped off between the boilers and the superheater and equipped with reducing vales, delivers low pressure saturated steam to the auxiliaries. The auxiliaries exhaust into a feed water heater. The boiler feed pumps draw their water supply from the condenser discharge.



LOAD CHART, ST. CLAIR TUNNEL COMPANY

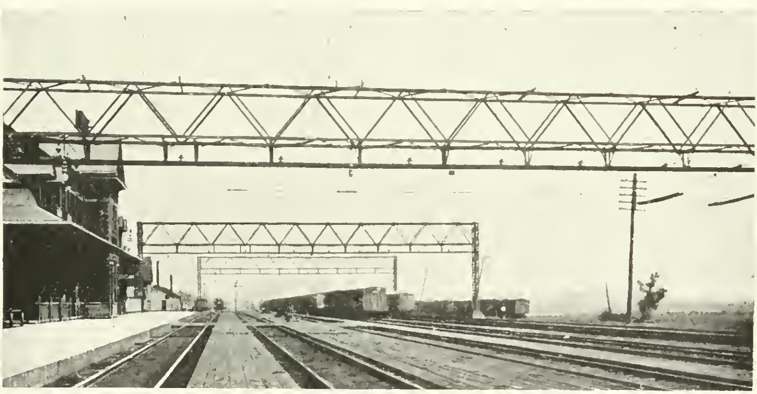
The switchboard and the guage board in the dynamo room enable the operator to see at a glance the condition of his plant and the load it is carrying. There are water meters in the boiler feed lines and wattmeters in the power lines. The customary log sheets are kept. The amount of coal used per month is ascertainable from the car load weights as the bunkers are brought to a uniform level at the end of each month.

The station was put in commission last November, at which time it was thoroughly tested out with an artificial load that corresponded to actual service conditions Later it was subjected to an official test and was found to more than meet the contract guarantees. The station has been operated from the start by the Tun-

nel Company's employees, although during the preliminary operating period the operation was nominally in the hands of the Electric Company. The station, while it is a simple one, contains refinements that good engineering demands. The load factor is necessarily bad, which fact, of course, is not conducive to economy. But the station has been designed to meet the tunnel conditions, and its economy is all that can be expected from a single track heavy grade freight load.

DISTRIBUTING SYSTEM

Just outside the power station there is a vertical shaft which extends to the tunnel. A reinforced concrete duct chimney has been built in this shaft as a continuation of the power station duct



VIEW OF PORT HURON PASSENGER STATION AND OVERHEAD CONSTRUCTION

lines. All the feeders pass from this chimney through holes in the tunnel shell into the tunnel. The locomotive feeders tap the trolley and rail at this point, which is the only distributing point for the entire trolley system. There are section breaks and switches for isolating particular sections of the trolley wires in case of accidents, but normally the trolley wires are continuous from the limits of the Port Huron yards through the tunnel to the limits of the Sarnia yards, a distance of 3.7 miles.

In addition to the locomotive feeders there are two feeders for the tunnel lights, two feeders for the Port Huron portal pump groups, two for the Sarnia portal pump groups, a three-phase power feeder and an arc light feeder for the Port Huron yards and similar feeders for the Sarnia yards. These cables are carried through the

tunnel in ducts which are supported by reinforced concrete beams and secured to the lining of the tunnel shell. There are two of these beams, one on each side of the tunnel. The ducts are covered with a three-inch layer of concrete. The feeders are paper insulated lead covered cables and terminate at the pump house switchboards, from which point the arc circuit and the three-phase power circuit continue as bare overhead wires.

In the yards a single catenary trolley construction is used. The spacing of the supporting bridges is 250 feet. There are no obstructions in the nature of intermediate supports, consequently where a number of parallel tracks are electrified the spans are long, as at the Port Huron passenger station where one of the spans is a little in excess of one hundred and forty-three feet. The bridges are tied together with guy cables. This enables a lighter construction to be used than if each bridge were sufficiently rigid, without the use of guy cables, to withstand the unbalanced strain resulting from the breaking of several messenger cables and trolley wires. The trolley wires are twenty-two feet above the tracks except in the tunnel and a short distance outside each portal. The overhead trolley leaves the yards clear of all electrical impediments while the catenary construction with its frequent trolley hangers practically eliminates the dangers arising from the presence of bare circuits.

In the tunnel a modification of the catenary construction is used. There are two parallel messenger cables and two parallel trolley wires. The messenger cables are supported on barrel type insulators spaced at intervals of twelve feet. These messengers carry the special double trolley hangers which are also spaced at intervals of twelve feet, but located three feet from the middle of the messenger span. This arrangement gives the required flexibility and at the same time avoids a dangerous vertical displacement of the messenger cables when the pantagraph bow passes under the trolley hanger. The clearance between the messenger cables and the tunnel shell is three inches. The trolley wires are six inches below the messengers which gives a minimum clearance of fifteen feet five inches between the trolley wires and the rail.

The tunnel is damp throughout a considerable portion of its length, consequently there was some doubt as to the advisability of attempting to carry 3 300 volt bare wires within three inches of the cast iron shell. Any fears that may have been entertained have proved to be groundless, for but two insulators have failed since

the electric locomotives were put in operation. The weak insulators were eliminated before the service was inaugurated by the use of breakdown tests which were continued until the overhead construction withstood a pressure of 4 500 volts.

The bonding in the tunnel, the building of the tunnel duct lines and the installation of the tunnel insulators was work of such a nature that it could be done a little at a time, consequently it did not seriously interfere with tunnel traffic. On the other hand stringing messenger cables and trolley wires is work of another sort. It was believed that the prosecution of this work would interfere with the tunnel service so seriously that it would be necessary to close the tunnel for two or three days and deflect the passenger and fast freight trains by the way of the Detroit ferries while the wires were being strung. This probably would have been necessary if continuous wires had been run from portal to portal as originally contemplated. The problem was solved by cutting the wires, running in from each portal and splicing at the middle of the tunnel. This arrangement enabled the work to be done in a short succession of brief stages that interfered no more with the tunnel traffic than the other tunnel work.

According to the agreement with the Railway Company, the Electric Company was to have two uninterrupted periods of two hours each in each twenty-four hours, provided it suited the convenience of the Railway Company. It turned out, however, that the most of the tunnel work was done during the slack period between 1 A. M. and 4 A. M. The stringing of the wires was accomplished in four such periods. The messenger cable reels were mounted on a flat car. The ends of the two cables were anchored at the American portal and the car let down the grade with the brakes. A box car served as a platform for the men who tied up the messengers. Before the foot of the grade was reached the brakes of the flat car were released and gravity carried the car well out on to the level section, after which it was barred to the middle of the tunnel. The box car, of course, had to be kept under control; consequently it had to be barred from the foot of the grade to the middle of the tunnel. The time required to run out and temporarily tie up the messengers from the American portal to the middle of the tunnel was two hours and thirty minutes. The two messengers were run in from the Canadian portal during the next period in the same way. Then the trolley wires were run in and tied up temporarily in the same way, after which the hangers were installed

and the trolleys spliced at the middle of the tunnel The feeder connections were then made and the faulty insulators eliminated

The tunnel is well lighted by 480 incandescent lights. These lamps are placed in two rows, one row on either side of the tunnel. They are spaced every twenty-five feet, but as they are staggered there is a lamp for every twelve and a half feet of tunnel length. The voltage of the lighting circuit is 440 volts, consequently the lamps are grouped four in series.

On account of the frequency, 25 cycles, it was impossible to use alternating-current arc lights, consequently a mercury converter was installed. There are two loops from the power station, one of which is for the Port Huron lights and the other for the Sarnia lights. The operation of the arc system is entirely satisfactory.

INSTRUCTING EMPLOYES

Before the overhead construction was put into commission all the railway employes having duties in the electric zone were schooled in the precautions to be taken with reference to the new equipment. The system was explained, the things to be avoided were pointed out and the action to be taken in emergency cases was indicated. Each one of the employes had to pass a written examination on this information before the Electric Company was allowed to turn on the power. The results have justified this rather extraordinary precaution on the part of the Railway Company since thus far there has not been a single instance of serious personal injury chargeable to the electrical installation.

DRAINAGE

There are some ten acres in the open cut of the American approach. This area drains towards the portal, at which point a pumping station is located. The pumping equipment consists of two motor-driven centrifugal pumps each of which has a capacity of 4 000 gallons per minute. There is also a motor-driven centrifugal pump having a capacity of 150 gallons per minute. The water is so trapped in a succession of basins that the rate of flow into the pump well does not ordinarily exceed the capacity of one main pump except in the case of heavy rain falls. The small pump handles the ordinary drainage. There is a similar pumping station at the Canadian portal, but, as the area is somewhat greater, each of the main pumps has a capacity of 5 500 gallons per minute. The

tunnel seepage is taken care of by two motor-driven centrifugal pumps, each of which has a capacity of 100 gallons per minute. The seepage pumps are located in the tunnel at the foot of the Canadian grade and discharge into a well at the Canadian portal. Six hours' operation per day for each seepage pump is sufficient to handle the tunnel leakage.

SERVICE

The tunnel division is protected by a block signal system which extends from summit to summit. The dispatcher's cabin is located at the Sarnia summit and the other signal cabin at the Port Huron summit. Telegraph orders are used. In addition to the written order the conductor receives a staff when the train enters the block. The switches and signals are locked until this staff is placed in the instrument at the other end of the block. The protection is so complete that not a single accident chargeable to dispatching has occurred during the eighteen years of tunnel service. There is a yard telephone system and in addition a special telephone line connecting the power station, the two signal cabins at the two portals, the middle of the tunnel and the roundhouse. The dispatcher is the master of the situation. He not only controls the train movements but the motive power as well. Any failure of power is immediately reported to him. In case it is trouble with a locomotive he has the engine replaced. In case it is trouble with the distributing system he orders the power cut off, then communicates with the electrical superintendent who takes charge of the repairs As soon as the repairs have been effected the dispatcher is advised and orders the power turned on again He is also advised as to any power station trouble that will interfere with train movements. There is no division of responsibility. This arrangement is the logical one since it is the dispatcher's business to get the trains through the tunnel. He must accordingly be supplied with the necessary motive power and be kept advised as to its availability. Likewise in case of trouble on the line he must protect the repairmen by keeping the power off until the proper authority has advised him that power can be turned on again.

Fortunately there have been but few occasions for the train dispatcher to exercise his authority as "load" dispatcher. There have been no power house failures. On two occasions there was a momentary interruptiton due to loss of vacuum. There have been no feeder failures. There have been no serious failures of the over-

head construction. On one occasion the trolley wire in the tunnel was burnt in two as a result of accidental contact with tunnel shell. The accident happened through careless resetting of the pantagraph of a work train locomotive standing in the tunnel. There was no occasion for the accident as the pantagraph can be reset without delivering a blow to the trolley wire. There have been momentary interruptions due to lightning arrester failures, the most of which have been occasioned by birds. There have been some minor troubles with switch contacts and pantagraphs, but nothing at all that could be classed as serious. This result is due to the reliability of the apparatus and the careful inspection and maintenance on the part of the Railway Company. No interference has been experienced in connection with the telephone and telegraph circuits. A telephone cable and telegraph cable extend the entire length of the tunnel. As has already been indicated the new service was inaugurated without any delay. It is now as much an established institution and as successful a service as that of any division of the system.

ENGINEERING

The Electric Company is the general contractor for the whole installation. Mr. Bion J. Arnold is the Railway Company's consulting engineer. The various parts of the work not directly in the line of the activities of the Westinghouse Companies has been executed by sub-contractors, but the Electric Company has been responsible for the installation as a whole, from the start to the finish. The contract involved a power station, a distributing system with its accessories, such as the pumping plants, arc and incandescent lighting and round house motors and most important of all, single-phase locomotives. The undertaking was a bold one as it was begun before the single-phase locomotive had demonstrated its capabilities in commercial service. Its successful operation is another notable achievement in electrical operation under severe steam railway conditions. It is undoubtedly being viewed with interest by railway men as an object lesson in what can be done to relieve the congestion of divisions with heavy grades. The record these locomotives have already made is a confirmation of the Electric Company's recommendation and the engineer's decision in favor of the single-phase locomotives.

THE ST. CLAIR TUNNEL SINGLE-PHASE LOCOMOTIVES

L. M. ASPINWALL AND G. BRIGHT

THE locomotives for the St. Clair Tunnel Company were designed to meet the conditions that exist in the handling of freight and passenger trains through the tunnel under the St. Clair river between Port Huron, Mich., and Sarnia, Ont., on the Grand Trunk Railroad. The locomotives are of the rigid frame type, having three pairs of drivers with a wheel base of 16 feet.

Weight and Capacity—The locomotives weigh 66 tons each and are generally used in pairs. Each pair is able to draw a 1 000 ton train through the tunnel and up the two percent grade, which re-

FIG. I—COMPLETE LOCOMOTIVE, ST. CLAIR TUNNEL COMPANY

quires a draw-bar pull of 50 000 pounds. The approaches to the grades are level and about 4 000 feet long. Each grade is about a mile long, while the one-tenth percent grade at the middle of the tunnel is one-third mile long. If it should become necessary to stop the train on the two percent grade, the locomotives can accelerate the train up to full speed, which is about 11 m.p.h. on this grade. The maximum safe speed of the locomotives is about 30 m.p.h., at which speed a double-header will exert a tractive effort of 6 000 pounds. The locomotives are designed to operate entirely on single-

phase alternating-current, which greatly simplifies the amount and layout of the apparatus. The voltage on the trolley wire is 3 300 volts.

Frame—The frames of the locomotives are of the rigid outside bar type, and consist essentially of two cast steel side frames joined at the ends by heavy cast steel bumper girders and reinforced by

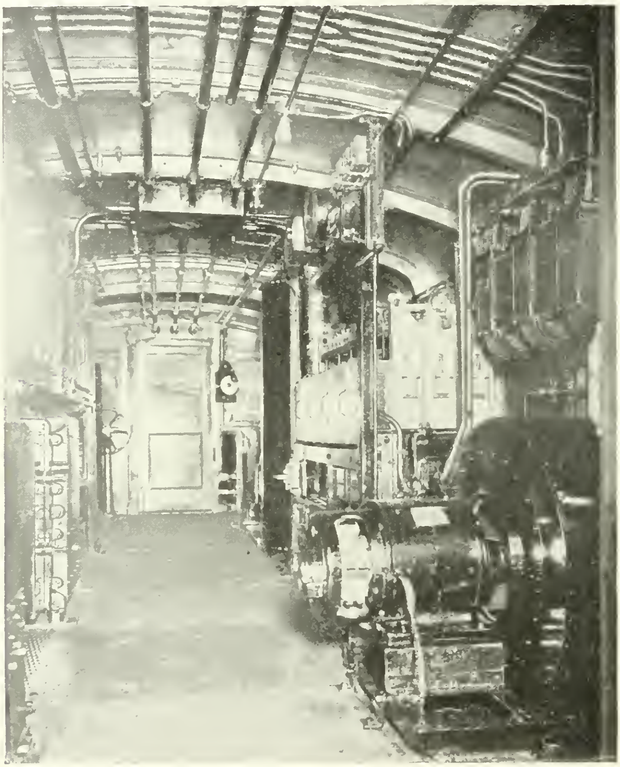


FIG. 2—VIEW OF INTERIOR OF ST. CLAIR TUNNEL LOCOMOTIVE

cross braces at two intermediate points. The main journal boxes are carried in the side frames in recesses fitted with gibb and wedges.

Driving Wheels—There are three pairs of driving wheels 62 inches in diameter. These drivers are built up with cast steel centers and steel tires secured in place by double "Mansel" retaining rings. The total weight of the locomotive rests on the drivers.

Cab—The cab is a superstructure of sheet steel with a Z-bar

frame built up on an angle iron base frame The auxiliary apparatus is arranged on each side of the cab leaving a wide aisle down the center. Trap doors are provided in the floor to render access to the motors easy. The locomotives are double ended, that is, a master controller and set of brake valves are mounted at each end of the cab so that the locomotive can be operated from either end. The apparatus in the cab is so laid out that any part can be readily inspected and replaced if necessary.

Figure 2, an interior view, shows clearly the manner of mounting the apparatus in the cab and the ample space through the center of the cab. All heavy currents are carried from one piece of apparatus to another in the cab by means of corded copper rods, while the smaller currents are carried by rubber insulated wire placed in conduits.

Motor Equipment—The motor equipment consists of three 250 hp single-phase railway motors, geared to three driving axles. These motors are of the ten-pole compensated type and are designed to operate at a normal voltage of 235 volts at a frequency of 25 cycles. The motors are connected in multiple and are so arranged that any one or two motors can be disconnected in case of trouble. The cut-out switches are designated by numbers and are mounted on the end of the reverse group. The motors are provided with air inlets, and ducts of ample size lead to these inlets from a blower so that forced ventilation can be effectively used. The blower also supplies air to ventilate the main auto-transformer. The continuous capacity of the motors under forced ventilation is 750 amperes at 235 volts. This rating would permit two locomotives to pull a 2 500 ton train at a constant speed of 15½ m.p.h. for any desired length of time on a straight level track.

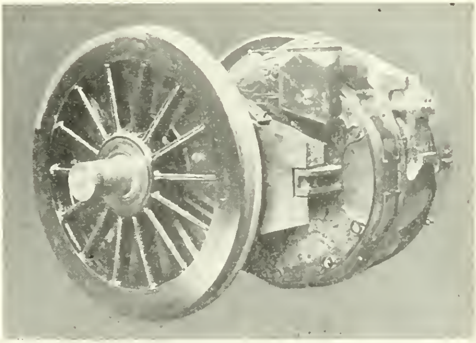


FIG. 3—MOTOR AND DRIVING WHEELS FOR ST. CLAIR TUNNEL LCCOMOTIVE

Control and Auxiliaries—The essential parts of the control system are:—One 3 300 volt auto-transformer, three preventive coils, a

train line relay, three switch groups, two master controllers, two small storage batteries and a small motor-generator set.

The main auto-transformer is located on the right side of the cab in the center. It is connected to the trolley by a high-tension cable through an oil circuit breaker provided with a no-voltage release protective relay. In case the locomotive should leave the rails and the frame thus become insulated from ground, this relay would cause the circuit breaker to open and remain open until the ground connection to the locomotive frame had been re-established.

The preventive coils, three in number, are located directly over the blower in the No. 1 end of the cab and provide a means of stepping from one transformer tap to another without producing a short-circuit in the transformer or an open circuit to the motors. At the same time they serve to distribute the motor current among the four switches in the transformer switch groups.

The train line relay is located between the transformer switch groups, its purpose being to enable a number of the wires leading from the master controllers to be used twice, thus cutting down the number of control wires required between locomotives when operating in pairs, and at the same time shortening the length of the controller drum.

There are three switch groups on each locomotive, two being transformer groups and the third the reverser group. The transformer groups are located above the transformer with the train line relay between them. Each group consists of ten electro-pneumatically operated switches. The function of these groups is to connect the motors to the various taps on the auto-transformer to give the requisite speed regulation. As these switch groups are very close to the transformer, the leads between the two pieces of apparatus are very short. The third switch group is located on the left side of the locomotive and consists of 12 electro-pneumatically operated switches. The switches in this group control the direction in which the locomotive is run. There are four of these switches for each motor, two for operation in the forward direction and two for reversing.

A master controller is located at each end of the locomotive on the right side, so placed that the engineer can have a clear view ahead from his seat and, at the same time, can easily operate the controller and brake valve handles. Each master controller has two

interlocking handles; one is the operating handle and the other the reversing handle. The master controller operates the various switches in the switch group by current from a 20-volt storage battery circuit and has 17 running notches and three switching notches. In the operation of the locomotives the controller can be left on any of the running notches as there is no resistance to overheat and burn out. This gives the alternating-current locomotive a very distinct advantage over the direct-current type where only two or three running notches are available. The switching notches are used only for running the locomotive without load at slow speed, as when passing over switches and frogs in the yards, and are passed over when handling a load. The engineer is guided in the operation of the controller by an ammeter mounted directly before him in the cab. In case the engineer operates his controller too fast, the circuit breaker will open and cannot be reset until he has thrown the controller handle to the "off" position. The circuit breakers on the locomotives are normally set to open when a current exceeding 4 500 amperes is taken by the motors. Across the top of the controller are located a number of push buttons which, when pressed, operate respectively the pneumatic bell ringer, pneumatic sanders, circuit breaker reset, and pantagraph trolley. Foot pedals are placed within convenient reach of the engineer's foot which also serve to operate the bell and sanders. The general principle of the operation of the control system is as follows: Air cylinders are used to operate the various switches and low voltage magnet valves to control the supply of air to the various switches. Two or more locomotives may be operated as one unit from any controller by inserting the proper "jumpers" between locomotives.

The ten cell (20 volts) storage batteries provided to operate the control magnets are in duplicate, one being in use while the other is being charged. The charging is done by means of the small 100 watt motor-generator set previously mentioned.

The air compressor is located beside the main reservoir on the left side of the locomotive. The maximum pressure used is 100 lbs., gauge pressure. A reducing valve lowers the pressure to 80 lbs. for use in the control system. The blower is located on the left side of the locomotive under the preventive coils. Both the compressor and blower motors are operated from low voltage taps on the main auto-transformer. In addition to the ammeters at each end of the locomotive a "motor" voltmeter, a "line" integrating wattmeter, and a "motor" indicating wattmeter are provided and are

located on the left side of the locomotive above the reversing switch group. Electric heaters are installed to heat the cab during cold weather.

Brake Equipment—The brake equipment is the standard double ended equipment, having an automatic and independent air brake valve at each end of the locomotive. A hand brake is also installed on each locomotive.

Current Collector—The current is collected from the trolley wire by means of a standard form of pantagraph trolley. Springs

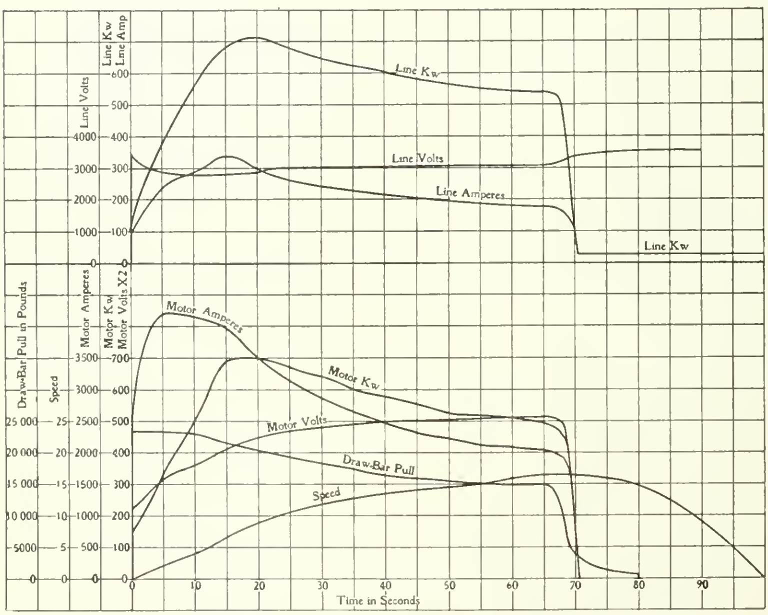


FIG. 4—CURVES SHOWING RESULTS OF TEST ON LOCOMOTIVE NO. 1305 ON THE INTERWORKS RAILWAY

Upper set of curves show line kw, line volts and line amperes. Lower curves show motor amperes, motor kw, motor volts, draw-bar pull and speed.

Gear Ratio, 16:85; size of wheels, 62 inch; weight of locomotive and cars, 565.7 tons; length of run, 1 628 feet; maximum speed, 16.5 miles per hour

are used to force the trolley up and hold it against the wire while compressed air is used to lower it, and to operate the locking mechanism.

Tests—Upon completion, each locomotive was given a very thorough test on the Interworks Railway at East Pittsburg. By means of a dynamometer car the draw-bar pull exerted by the loco-

motives under various conditions was accurately measured. By setting the brakes on the train and keeping the locomotive brakes released, a draw-bar pull of 45 000 lbs. was obtained repeatedly, with a single locomotive on clean dry rails, without sand. Tests were also made showing the ability of the locomotive to start and accelerate trains of various weights and to show the capacity of the motors in continuous service. All of the tests have given most gratifying results and have been substantiated by the operation of the locomotives in regular service. Fig. 4 shows the results of a test made on locomotive No. 1305, accelerating a trailing load of 500 tons on a slight grade on the Interworks Railway. This curve shows very clearly how a high initial acceleration can be obtained with a comparatively

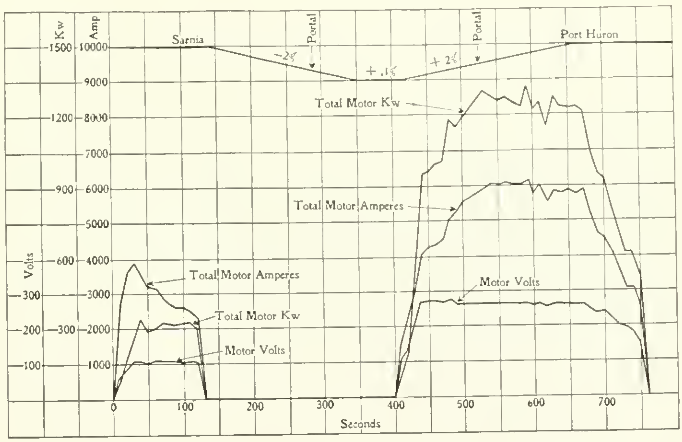


FIG. 5—CURVES SHOWING RESULTS OF TESTS ON A DOUBLE-HEADER LOCOMOTIVE ON A RUN THROUGH THE ST. CLAIR TUNNEL

low consumption of power. The draw-bar pull is considerably less than it would be if constant speed were attained on account of the inertia of the locomotive which takes an appreciable percentage of the tractive effort during acceleration. As the test run from which these curves were derived was made on an up grade, there was practically no drifting, hence the watt-hrs. per ton-mile are somewhat high.

The results of a test made in actual service with two locomotives drawing a 900 ton train through the tunnel are shown in Fig. 5. The motor amperes, motor kw and motor volts have been plotted and direct comparison of the curves can be made with reference to the grade conditions as given on the profile.

DEVELOPMENT OF THE DOUBLE FLOW STEAM TURBINE

R. N. EHRHART

THE greater part of the turbine-generating units have been built of the alternating-current type designed for frequencies of either sixty or twenty-five cycles. Generating units having other characteristics may be regarded as special and not definitely associated with the fixed line of standards. In small sixty-cycle units, 3 600 revolutions per minute is regarded as the standard speed, and 1 800 or 1 200 revolutions per minute for sizes from 1 000 to 3 500 kw. For the larger sizes of 5 000 kw and upwards, 720 revolutions has been the standard speed until the introduction of the double flow type of turbine. Twenty-five cycle units up to 3 500 kw operate at 1 500 revolutions and similarly the standard speeds for units larger than 5 000 has been 750 revolutions. In the double flow turbines for capacities of 5 000 kw and upwards the speed of twenty-five cycle units as well as sixty cycle units has been modified.

Recent advances in the art of turbine-generator construction have made it possible to build generators of capacities as high as 10 000 kw to run at speeds of 1 200 and 1 500 revolutions per minute for sixty and twenty-five cycles respectively. Heretofore 720 and 750 revolutions per minute were considered the highest speeds which were feasible. It was realized that the single flow turbine if used at such high speeds and powers as proposed for the new line of generators, would have certain limitations, and that a new type of turbine could be evolved that would meet the conditions more satisfactorily than any modifications of the standard single flow type.

The difficulties encountered in designing single flow turbines for the conditions specified and the reasons for the particular design of double flow turbine which has been developed are given below.

DIFFICULTIES IN DESIGNING SINGLE FLOW TURBINES FOR THE NEW LINE OF GENERATORS

The limit in rated capacity of single flow Parsons turbines operating at 1 500 revolutions has been regarded as somewhere between 3 000 and 5 000 kw. This limit is chiefly imposed by the proportions of the low pressure and exhaust parts of the turbine.

In a conventional design for 3 500 kilowatts, the exhaust pipe is about as large in diameter as the turbine casing. The diameter of the casing is dependent on the diameter of the rotating part, and the diameter of the rotating part is fixed by its ability to stand the centrifugal stresses due to the high speeds of revolution; hence the maximum permissible diameter of the turbine casing is, to a great extent, dependent on the speed. For the high speeds suggested for generators as large as 10 000 kw, the conventional exhaust pipe on the turbine would have to be of such size as to make it disproportionately large compared with the turbine; indeed, larger than the turbine casing could easily accommodate. Also, the blades in the low pressure part of the turbine would have to be made correspondingly long to accommodate the steam represented by 10 000 kw; in fact, of such a length that they would be impracticable.

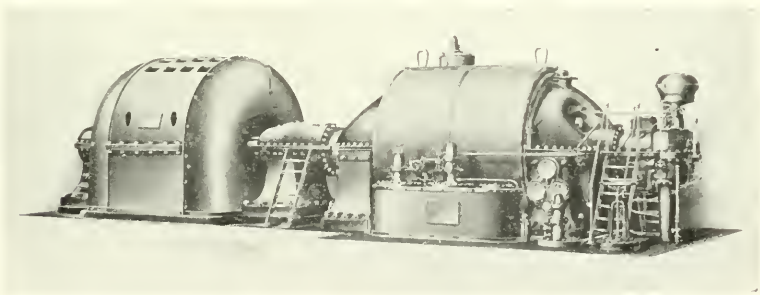


FIG. 1—10 000 KW DOUBLE-FLOW TURBINE GENERATING UNIT

The above, in connection with some minor points, made it evident that there would be considerable difficulty in the aggregate in designing a single flow turbine to meet the stated conditions of speed and power.

CHOICE OF THE NEW DESIGN

Before designing the double flow turbine, a general survey was made of the modern developments in turbine work. In view of the high economies attained by the Parsons turbines, the conclusion was reached that, to attain the highest efficiency, the major part of the turbine should be designed along the same lines. In this type of turbine, however, the high pressure portion, dealing with the high pressure incoming steam, is necessarily the least efficient. The reason for this is that the lengths of the blades are about in proportion to the specific volume of the steam and consequently the initial expansions in the turbine require blade passages of very small dimen-

sions since they are dealing with steam of high pressure and small volume. This means that the leakage past the tips of the blades is relatively greater than in the low pressure elements where the blades are long to accommodate the larger steam volume after expansion through the various parts of the turbine.

It thus became evident that the least efficient part of the turbine

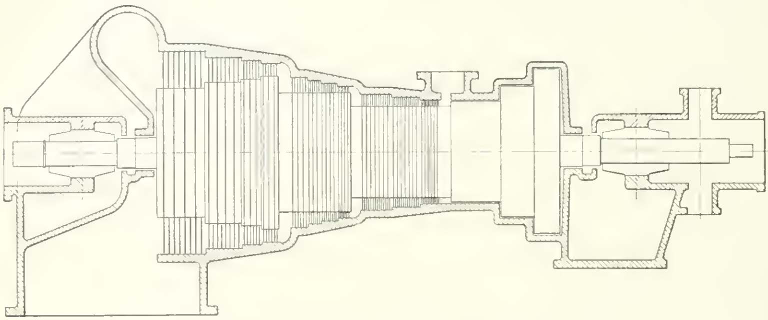


FIG. 2—CONVENTIONAL SKETCH OF SINGLE FLOW TURBINE

might have some other type substituted for it, provided the efficiency of the element substituted was not less than that of the element removed, and that sufficient mechanical and structural advantages resulted from the substitution.

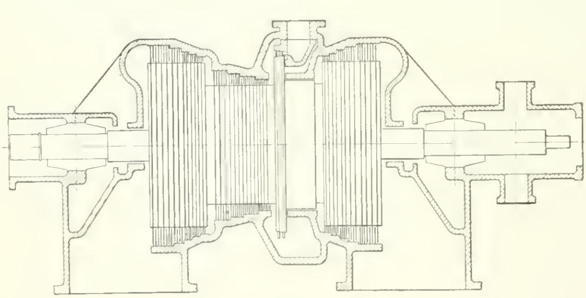


FIG. 3—CONVENTIONAL SKETCH SHOWING GENERAL ARRANGEMENT OF PARTS IN THE DOUBLE FLOW TYPE OF TURBINE

An impulse turbine consisting of a revolving wheel of large diameter with nozzles directing the steam against the wheel, obviously presents some advantages. The dimensions in an axial direction can be made much less than in a corresponding Parsons element and a larger diameter makes it possible to design the entire turbine with a casing of nearly uniform diameter. On account of the large

diameter of the impulse wheel only a portion of the circumference is needed for the supply nozzles. These can easily be grouped in isolated chambers which are not an integral part of the turbine casing, so that the high temperature, high pressure steam does not come in contact with the main casing. By the time the steam gets into the main cylinder it has converted a part of its heat energy into work, and consequently it is of a moderate temperature, thus the possibility of distortion due to high temperature steam is greatly decreased.

The high pressure impulse element is not subjected to serious leakage losses since the nozzles are, in effect, connected directly to the steam line. This is true only in the case of the high pressure impulse element. In a multi-stage impulse turbine there is a certain amount of leakage from chamber to chamber where the shaft runs through the separating diaphragms. The adoption of the impulse element for the new turbine can be characterized as taking the best element of the multi-stage turbine and substituting it for the least efficient element of the Parsons turbine.

Difficulties incident to the design of the low pressure part of the Parsons turbine in one element to operate at high vacuum at 1 500 revolutions with a capacity of 5 000 kw or over, are absent in the double flow turbine in which the low pressure element is divided into two parts. The blades can be made one-half the length and the exhaust pipe divided into two parts, each of reasonable size.

As a concise summary of the foregoing, the development of the double flow turbine design may be shown to be due to:—

1—Development along electrical lines, enabling generators of high power to be operated at speeds hitherto not considered.

2—Realization that a new type of turbine would have to be developed to comply with the high power, high speed generators on account of the difficulty in designing the low pressure and exhaust parts in the conventional way.

3—Since a new design was necessary, incorporation of the new principles tending to structurally improve the turbine without sacrifice in economy, was considered.

ADVANTAGES OBTAINED BY THE ADOPTION OF THE DOUBLE FLOW LOW PRESSURE ELEMENT

1—Low pressure blades may be made of reasonable length.

2—Exhaust passages may be made moderate in size.

3—Low pressure balance piston can be omitted since one low pressure part balances the other.

ADVANTAGES OBTAINED BY THE ADOPTION OF THE HIGH PRESSURE IMPULSE ELEMENT

1—The turbine is shortened thirty percent, consequently the casing and rotating parts are more rigid as regards distortion and deflection.

2—The diameters of casing and rotating parts are more uniform, thus tending to greater rigidity.

3—The high pressure steam is isolated in relatively small chambers; the main casing is not in contact with high temperature, high pressure steam.

A comparison of the double flow design and the design of a conventional single flow turbine is shown diagramatically in Figs. 2 and 3. Both designs represent turbines of the same power and speed. In Fig. 2, which shows the conventional type of single flow turbine, the disproportionate dimensions of the low pressure exhaust casing may be clearly seen. Fig. 3 shows the general arrangement of the double flow turbine from which the advantages already mentioned can readily be recognized.

The double flow turbine does not in any way supersede the single flow turbine that has come to be so well known. It has invaded a new field involving the use of generators of very large powers having speeds greater than previously thought feasible. In sizes up to 3 500 kw the single flow turbine has established itself as the most suitable prime mover, but it is generally conceded that for the high speeds and powers of electrical generators now available, the double flow design is preferable.

FOREIGN SINGLE-PHASE ELECTRIC ROADS

Manufacturers		Westinghouse	Siemens Schuckert Werke	Allgemeine Elektricitats Gesellschaft	Maschinen Fabrik Oerlikon	Miscellaneous	Totals
No. Roads — In operation	A.C.	5	10	11	3	1	30
	A.C. & D.C.	2	1	....	....	....	3
No. Roads — Under Construction	A.C.	3	....	....	....	....	3
	A.C. & D.C.		....	....	....	....	....
Total,		10	11	11	3	1	36
No. Miles of Road — In operation	A.C.	68.75	81.32	537.98	46	1	735.05
	A.C. & D.C.	14.0	20	....	....	....	36
No. Miles of Road — Under Construction	A.C.	57.75	....	....	....	....	57.75
	A.C. & D.C.	....	....	....	....	....	....
Total,		140.50	101.32	537.98	46	1	828.80
No. Cars	A.C.	34	55	99	3	1	192
	A.C. & D.C.	16	14	....	....	....	30
Total,		50	69	99	3	1	222
No. Locomotives	A.C.	15	26	....	2	....	43
	A.C. & D.C.	....	....	....	....	....	....
Total,		15	26	....	2	....	43
Motor hp.	A.C.	6 260	22 250	29 730	1 880	100	60 220
	A.C. & D.C.	1 700	2 240	....	....	....	3 940
Total,		7 960	24 490	29 730	1 880	100	64 160
Range of trolley potential—volts		3 300 to 18 000	500 to 20 000	600 to 10 000	5 000 to 15 000	500	500 to 20 000
Countries where used		Italy Sweden France England Norway	Switzerland Holland England Italy Austria Prussia	Prussia Sweden England Austria Belgium	Switzerland	Experimental Line Compagnie Generale Parisienne	Italy Sweden France England Norway Holland Austria Prussia Switzerland Belgium

ELECTRIC RAILWAY ENGINEERING—IX

LOW-TENSION DISTRIBUTING SYSTEM

F. E. WYNNE

THE usual low-tension distributing system for an interurban railway comprises the track rails, bonding, trolley line or third rail and feeders. Local laws make it necessary in certain cities to use the conduit system and in others a double trolley or other insulated metallic return for the purpose of avoiding electrolysis in adjacent pipe lines. The present consideration of this subject is confined to the overhead trolley and third rail with track return, as the general principles involved in determining the sizes of conductors are the same for all of the several systems.

TRACK

Ordinarily the size of track rail is determined by physical, rather than electrical conditions, the principal factors being the weight of cars or trains, speed and kind of ballast. The rail weights are chiefly from 60 to 85 pounds per yard, with 70 and 75 pound rails the most common. The resistance of steel rails is somewhat dependent upon the impurities in the iron. The resistance of ordinary rail steel runs 9.5 to 10.5 times the resistance of copper of equal sectional area. These values are for the rails alone, and do not take into consideration the additional resistance of the bonds. The percentage by which the resistance of the rail alone should be increased for practical use is a variable depending upon the size and length of the bond. The conductivity of the bonds, including contacts is most often from one-fourth to one-half that of the rail, and one-third may be taken as an average. Using this value, the effect of a bond is to add to the rail resistance between bonds an amount equal to the resistance of a section of the rail three times the length of a bond.

For example, take 30 foot rails bonded with two No. 000, nine-inch bonds per joint:—

Length between bonds	351	inches
Length of bond × 3	27	"
Equivalent length of rail	378	"
Actual length of rail	360	"

The ratio of resistance of rail and bonds to rail alone = 378 ÷ 360 = 105 percent. Taking this ratio and assuming the resistance of

the rail alone to be ten times that of copper, it will be seen that the effect of the increased resistance at joints is, in this instance, equivalent to increasing the resistance of the steel rails from 10 to 10.5 times that of copper.

Because of the variations in the quality, length and size, a track resistance of bonds and rails equal to eleven times the resistance of an equal cross-section of copper may in general be used, without serious error, and on this basis the curves in Fig. 1 are made. Of

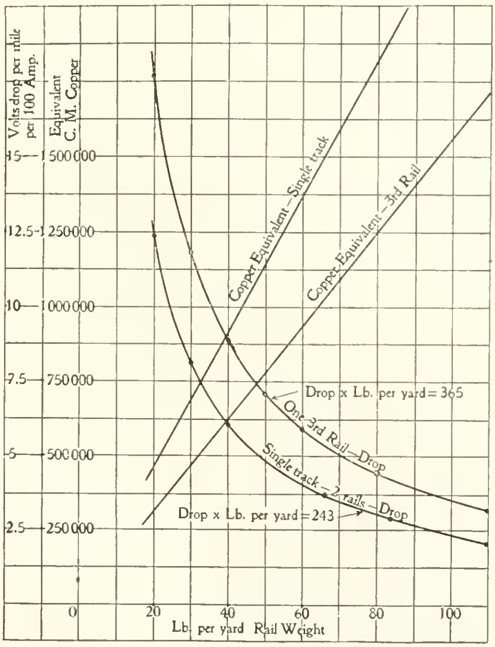


FIG. 1—CURVES SHOWING VOLTAGE DROP IN RAILS OF VARIOUS WEIGHTS, PER MILE PER 100 AMPERES AND THE EQUIVALENT C. M. COPPER FOR RAILS OF VARIOUS WEIGHTS FOR SINGLE TRACK AND FOR THIRD RAIL

course it is more satisfactory to use the exact value for each particular case if this value can be obtained. This, however, is not often possible; hence the necessity for a general average value as given above.

THIRD RAIL

For third rail construction it is possible to obtain high conductivity steel. Such steel is not suitable for track rails because of its

softness, but may be used for the third rail without excessive wear, since the pressure of the contact shoes on the rail is comparatively small. The third rail bonding should be about twice as heavy as that of the track rails since twice as much current passes through the third rail as through each of the track rails. An average value for third-rail resistance, including bonds, is eight times the resistance of copper of equal cross-section. On this basis, curves for third rail are also shown in Fig. 1. The trolley or third rail forms the positive side of the line and the track is the negative side or "return," as it is commonly called. Either or both sides may be supplemented by feeders connected in parallel with them. Except for heavy work, the trolley only is thus reinforced.

LINE VOLTAGE REGULATION

The determination of the proper amount of copper in the overhead circuit or the size of third rail, is usually an application of Ohm's law:—E=IR. The maximum allowable voltage drop, *E,* is the difference between the voltage supplied by the power house or sub-station and the minimum voltage permissible at the car. The pressure supplied may be taken at 600 volts. This voltage is a commonly accepted standard, but considerable variation either way from this value is found in special cases. The minimum voltage at the car should never be less than 300 volts, and for high-class service a minimum of 350 volts is much better; hence the allowable drop from station to car is from 250 to 300 volts. The maximum current is determined from the current taken by the car equipments and the distribution of the cars. The current per car is dependent chiefly upon the car weight, rate of acceleration and gear ratio. At times the maximum current is affected by the profile of the line. The resistance *R* is the resistance of the series circuit of conductor and track from station to car, the paralleling feeders being taken in connection with the trolley or third rail as forming the supply circuit and the return circuit as consisting of the track rails and whatever feeders may be in parallel with them. Since the track without feeders usually constitutes the return circuit, the track drop for a predetermined current and distance is easily found. By subtracting the track drop from the total drop, the drop in the supply circuit is obtained. The result obtained from dividing this drop in the supply circuit by the product of current (expressed in 100-ampere units), and distance (in miles), gives the volts drop per mile per 100

amperes. Reference to Figs. 2 and 3 gives the total cross-section of copper required in the supply circuit. The division of this total into commercial sizes of conductors and feeders is a matter largely dependent on the particular case in hand and will be considered later. Fig. 3 also gives the weights and diameters for standard cables.

The car equipment best adapted for the project under consideration having been determined, the condition of maximum drop may be determined. It is dependent upon the distribution of cars and location of power-house and sub-stations. The location of sub-stations is more or less dependent upon the maximum permissible drop, so that those two items should be considered simultaneously, which can best be done with the assistance of a graphical train sheet.

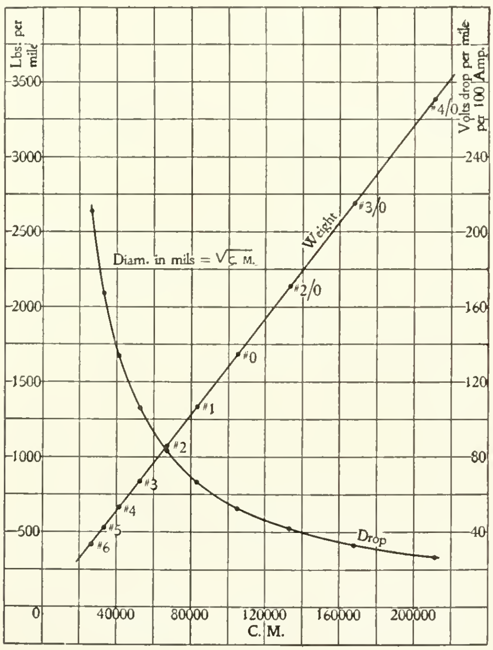


FIG. 2—CURVES SHOWING WEIGHT IN LBS. PER MILE OF VARIOUS SIZES OF FEEDERS AND THE VOLTAGE DROP PER MILE PER 100 AMPERES FOR VARIOUS SIZES OF COPPER WIRE

USE OF TRAIN SHEET

The train sheet* is primarily a graphical method of showing the

*The train sheet and its uses are also described by Mr. E. P. Roberts in the *Street Railway Journal* for November 23, 1901.

location of the several cars in service on the line at any and all hours of the operating day. It also shows the headway, layovers, location of turnouts, variations in schedule speed, different classes of service and towns. On the same sheet it is useful to show the track layout, trolleys, feeders, and high-tension lines and location of power house and substations. The following specific case will illustrate the fore-

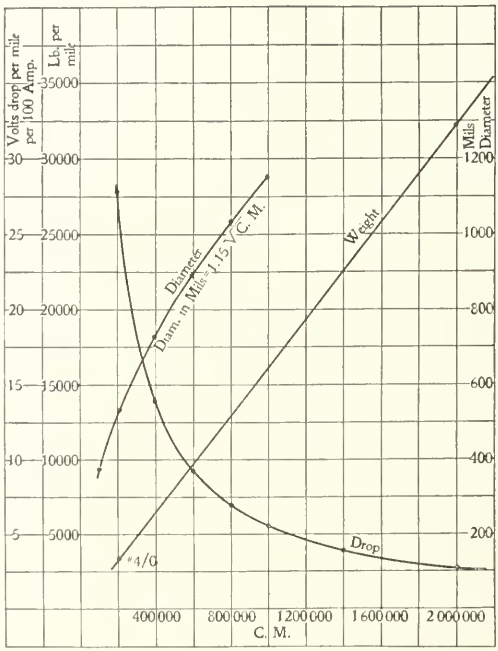


FIG. 3—CURVES SHOWING VOLTAGE DROP PER MILE PER 100 AMPERES FOR LARGE SIZE FEEDERS, ALSO THE WEIGHTS PER MILE AND DIAMETERS OF LARGE FEEDERS

going principles and will also serve to make clear some features of the general problem.

ILLUSTRATIVE PROBLEM

Assume that a 45-mile line running between the cities of *A* and *J* and passing through the towns and villages *B*, *C*, *D*, *E*, *F*, *G*, *H* and *I* is to be installed and operated by direct-current motors, the source of power being an alternating-current station located along the line of the railway at a point 15.2 miles from the terminal in *A*, and that each car will be equipped with four 75 hp direct-current

motors. The train sheet, Fig. 4, drawn between distance as a base and time as ordinates, shows the service to be given. The regular schedule is maintained by passenger cars operating under a one-hour headway in each direction, local and limited cars alternating. On Saturdays, Sundays and holidays enough local passenger cars are operated to reduce the headway to one-half hour in each direction. In addition to the passenger service, two cars for handling express matter and light freight, make two round trips each per day, six hours being allowed for each round trip, including all stops and lay-overs. For three miles within the city *A*, the cars operate over a double track section of the city railway system at a schedule speed of ten miles per hour, thus taking 18 minutes to traverse this city trackage. The double track extends one mile beyond the city limits. In the city, *J*, the cars enter on one street and leave on a parallel street, thus making a loop four miles in length, with a terminal two miles from the city limits by either route, the two sides of the loop being separated by one or two city blocks. The schedule speed in this city also is ten miles per hour. Between *A* and *J*, the local cars make the run of 40 miles in one hour, 25 minutes, at a schedule speed of 28.24 miles per hour when making one 20-second stop every two miles. The limited cars make this interurban portion of the run in one hour, ten minutes, at a schedule speed of 34.3 miles per hour, stopping for 30 seconds at each of the eight intermediate towns and sub-station No. 2 only. The sizes of the towns and villages are not such as to require any speed limits within their boundaries. The express cars have an average speed between stops about equal to that of the local passenger cars, but the schedule will be lower because of the comparatively long stops at towns for loading and unloading, and the stops at turn-outs to let passenger cars pass. The turn-outs can be located as indicated on the train sheet. Through turn-outs have been placed at the meeting points of the trains operating on the regular schedule, and stub turn-outs at the meeting and passing points where one of the cars is an extra.

SUB-STATION LOCATION

Through sub-stations, the power house at *D* supplies power for the entire line, except the three miles in *A*, on which section the cars receive power from the city system. Where storage batteries and boosters are not employed, sub-stations may be located from eight to fourteen miles apart in interurban service, the distance depending upon the frequency of service and the capacity of the

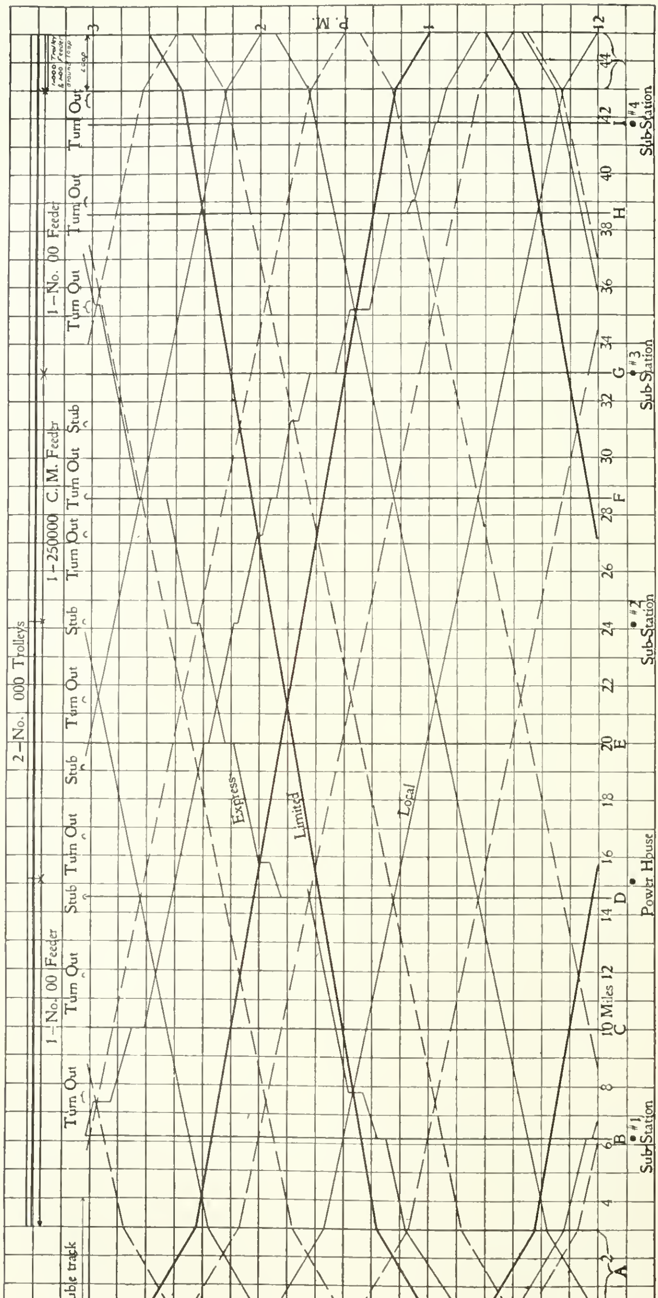


FIG. 4—TRAIN SHEET FROM 12 M. TO 3 P. M.

car equipments. The distance from *A* to the power-house is 12.2 miles, therefore one sub-station is needed on this section in addition to the rotary converters in the power station itself. This sub-station should preferably be located at a town so that the attendant may act as ticket agent also. To secure good voltage regulation with a minimum amount of copper in the low-tension distribution system, the sub-station should be located between the city limits of *A* and the power house at a point such that the distance between sub-station and power house is approximately three times the distance between the sub-station and the city limits of A. This rough general rule is based on the fact that a study of numerous interurban systems, both operating and projected, indicates that the maximum load fed from one sub-station alone is from two-thirds to three-fourths of the maximum load found between two sub-stations and drawing power through both of them. Also the minimum voltage is found in one case at the end of the section fed from one point only, and in the other case most frequently about midway between feeding points. Therefore, practically the same voltage regulation is obtained in both cases by using the same sizes of trolley and feeder throughout and proportioning the distances as above specified. Guided by these considerations, sub-station No. 1 is located at the town *B*, 3.2 miles from the city limits of *A* and nine miles from the power house.

Between the power house and the terminal in *J*, a distance of 29.8 miles, not less than two sub-stations should be installed, one being at *F* and the other at *I*. It is probable that a better arrangement would be to have three sub-stations on this section, one at *I*, one at *G*, and the third about midway between *E* and *F*. Therefore, a comparison of these two arrangements should be made on the basis of first cost, maintenance, depreciation, operating expenses and reliability of service before a final selection is made. Such a comparison shows that the layout employing three sub-stations is the better in this case. Hence the determination of copper for that arrangement only will be here described. The several sections will be considered separately.

CALCULATION OF TROLLEY AND FEEDER SIZES

Section I—City limits of *A* to sub-station No. 1—As a starting point, take 250 volts allowable drop. The train sheet shows that trains are due to meet at the end of the single-track section, 2.2 miles from the sub-station. This load comes 20 minutes after every

even hour. A car with a specified equipment requires about 500 amperes for starting and about 240 amperes as the average current for running. When two cars meet it is reasonable to assume that the maximum current will be due to one car starting and one car running at its average current. Therefore, in this case the total current is 740 amperes and the distance over which this current is fed from the sub-station is 2.2 miles. The total allowable drop per mile per 100 amperes is, therefore, $250 \div (2.2 \times 7.4) = 15.35$ volts. From Fig. 1, it is seen that the portion of this total allowable drop which occurs in the 70 pound single track is 3.5 volts. Hence, the overhead drop is equal to $15.35 - 3.5 = 11.85$ volts per mile per 100 amperes. Reference to Fig. 3 shows that this corresponds to a total cross-section of overhead copper of 464 000 cir. mil. Fig. 2 shows that two No. 000 trolleys are equivalent to 336 200 cir. mil. Assuming that these trolleys will be used, the feeder copper necessary is 464 000—336 200=127 800 cir. mils. Fig. 2 shows that the nearest commercial size is No. 00=133 225 cir. mils. Using this size of feeder the actual drop is reduced to 15.22 volts per mile per 100 amperes, or 248 volts total.

It is doubtful whether the above represents the condition of maximum drop for this section since at 18 minutes after every even hour there is a local car starting at the city limits and a limited car running at a point 1.1 miles from *B* toward *A*. This gives the following situation: A total of 740 amperes is fed over single track 1.1 miles from *B* to a limited car which takes 240 amperes, the remaining 500 amperes being fed over 1.1 miles of single track from the limited car to the beginning of the double track and then one mile over double track to the local car. All of the above steps are in series and therefore the total drop at the local car which is starting will be the sum of the three separate drops figured from above. Assuming the amount of overhead copper, as previously figured, i. e., two No. 000 trolleys and one No. 00 feeder; the drop per mile per 100 amperes is 15.22 volts for single track trolleys and feeders and 13.47 volts for double track with the same trolleys and feeders. Hence the total drop is $(1.1 \times 7.4 \times 15.22) + (1.1 \times 5 \times 15.22) + (1 \times 5 \times 13.47) = 275$ volts. This drop may be considered satisfactory as the maximum permissible in this instance. Incidentally, it shows that the first condition chosen was not the worst possible on this section, and that it is well to figure out the drop for several points if an inspection of the train sheet leaves any doubt as to which is the worst case for drop.

Section II—From sub-station No. 1 to the power house, the distance is about nine miles. The condition of maximum drop may be taken as due to two cars meeting between these two feeding points at a point 3.4 miles from the power-house and 5.6 miles from sub-station No. 1. For a trial assume the same amount of copper as in *Section I*. The total current, 740 amperes, divides in inverse proportion to the distances from the respective stations. From sub-station No. 1, the car will receive $(3.4\times740)\div9=279$ amperes over a distance of 5.6 miles. Hence the drop is $(5.6\times2.79\times15.22)=$ 238 volts. This is somewhat less than the maximum permissible, but should be allowed to stand, as it would hardly be worth while to string a feeder smaller than No. 00, and the trolleys alone are not sufficient.

On this section the drop that occurs with three cars (one starting and two running) at the turnout 1.6 miles from sub-station, No. 1 may also be determined: The total current is 980 amperes, 806 amperes of which are drawn from sub-station No. 1, giving a drop of 196 volts, which is well within the limit.

Section III—From the power house to sub-station No. 2 the distance is nine miles. The maximum drop occurs when there are two cars at the turnout 3.8 miles from the power house and taking 428 amperes from it. Assuming the same copper as before the drop is 248 volts, which is satisfactory.

Section IV—From sub-station No. 2 to sub-station No. 3 the distance is 8.8 miles and the condition of maximum drop occurs with three cars at the turnout midway between stations and taking 490 amperes from each. A rough estimate shows that the No. 00 feeder as previously used will not be sufficient on this section. Following the same process as outlined in *Section I*, it is found that the total permissible dop per mile per 100 amperes is $275\div(4.4\times4.9)=12.75$ volts. Taking out the 3.5 volts for track drop, the remainder of 9.25 volts is that permissible in the overhead copper. Reference to Fig. 3 shows 595 000 cir. mils. as the total copper required. Subtracting from this 336 200 cir. mils. for the two trolleys, the area of the feeder copper required is 258 800 cir. mils. The nearest commercial size 250 000 cir. mil. cable should be used. With this feeder the maximum drop under the above conditions is 279 volts. This slight excess over the arbitrary limit of 275 volts may be permitted here since this bunching of three cars is avoidable except on those days when the extra local passenger service is in operation.

Section V—From sub-station No. 3 to sub-station No. 4 the distance is 8.8 miles. Under the worst conditions there are three cars at the turnout 2.6 miles from sub-station No. 3, taking from it 690 amperes. With the No. 00 feeder the maximum drop is found to be 273 volts, which is within the limit

Section VI—From sub-station No. 4 to the terminal in *J*, the distance is 3.2 miles, 2 miles of which are practically double tracked, since the two sides of the loop may be electrically tied together. Generally there is a tendency toward the bunching of cars at terminals in view of which fact some extra feeder capacity may be required on this section. To allow for this, a trial may be made on the basis of two No. 000 trolleys and one No. 00 feeder on the single track portion outside of *J* and one No. 000 trolley in parallel with one No. 00 feeder extending entirely around the loop whose sides are tied together, so that electrically the loop is equivalent to double track with one No. 000 trolley and one No. 00 feeder to each track.

The condition of maximum drop on this section comes with a local car starting from the terminal in *J* and a limited car running in *J*, 1.6 miles from *I*. Then the drop is $(1.2 \times 7.4 \times 15.22) + (0.4 \times 7.4 \times 10.9) + (1.6 \times 5 \times 10.9) = 255$ volts, which shows that the assumption that extra feeding capacity would be required at this point was justified, and that the amount chosen is suitable. A summary of the results of the above calculations is shown by the trolley and feeder layout on the train sheet, Fig. 4.

It should be noted that the foregoing calculations are all based upon the conditions of maximum service which is obviously reasonable since the continued maintenance of first class service is largely dependent upon good voltage regulation under the worst conditions. The proper requirements here work out very well, only two sizes of feeder being necessary. It is an advantage to minimize the number of sizes of feeder copper, in so far as may be possible without entailing poor voltage regulation on some sections and an excessive amount of copper on others.

This example might have been worked out using a third rail on the interurban section instead of trolleys and feeders. The size of third rail would have been selected from Fig. 1 by referring to it for the equivalent total amount of copper required, for each section as determined above for section *I*. One size of third rail should be

used throughout, as there is little difference between the exact sizes required on the several sections and a uniform construction greatly facilitates the work of installation.

SELECTION OF CONTACT LINE

In general, for light and moderate service, the overhead trolley is to be preferred and is necessary on city streets and highways. For heavy direct-current work at the usual voltages, where the currents are very large, the third rail is unquestionably preferable to the overhead trolley where local conditions do not make the use of the latter imperative. Of course certain cases arise which show that a good engineering layout may be obtained with either trolley or third rail at practically the same first cost and giving the same running expenses. In such a case, local conditions would be the determining factor in the selection. Further generalization on the subject of choosing the proper conductors for an electric railway system cannot be made without a somewhat detailed consideration of local conditions. The variety of these is so great that it would be beyond the scope of the present article to attempt even a reasonably complete outline of them.

The choice of size and number of trolley wires in the above example was made for the following reasons: Sizes smaller than No. 000 wear rapidly. No. 000 trolley wire is considerably easier to handle than No. 0 000. This tends to reduce the labor and cost of erection. Two No. 0 000 trolley wires would have been inadequate without a feeder. The high speed schedule makes it advisable to use twin trolleys instead of a single wire, because the same amount of copper would have to be installed in either case and twin wires avoid frogs in the trolley at switches, so that it is possible to pass the switches at higher speeds without fear of the troubles which occur when the trolley wheel leaves the wire. Furthermore, on entering and leaving switches, no attention has to be given to the trolley pole as is the case with that type of construction in which the side trolley wire at switch points parallels the main trolley without joining it. An objection to twin wire construction is that accidents to the trolley structure are liable to result more disasterously. At the same time, twin wires remove one of the most frequent sources of damage to the overhead work; i. e., the trolley wheel leaving the wire at frogs.

WEIGHTS

Having determined the proper sizes of trolley and feeder, the weight of copper required is easily obtained from Figs. 2 and 3. From these unit weights the following total weights are obtained:

84 miles No. 000 trolley @ 2687 lb.	225 708 lbs.
35.2 miles No. 00 feeder @ 2129 lb.	74 941 "
8.8 miles 250 000 c.m. feeder @ 4026 lb.	35 429 "
Total	336 078 "

This amount should be increased by about 2.5 percent to allow for

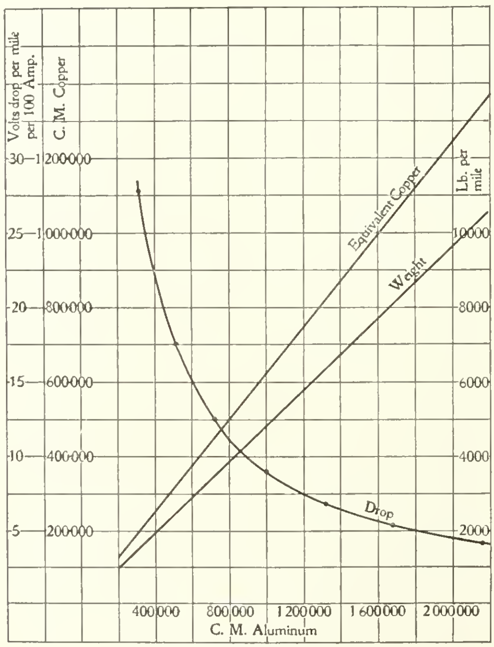


FIG. 5—CURVES FOR ALUMINUM FEEDERS OF VARIOUS SIZES SHOWING VOLTAGE DROP PER MILE PER 100 AMPERES, EQUIVALENT COPPER AND WEIGHT PER MILE

the extra length taken up by sag and curves, hence the total amount of copper required is 334 480 lbs.

If aluminum feeders are desirable or necessary, the calculations may be made in terms of copper by the method described and the equivalent sizes of aluminum together with the weights may be taken from curves in Fig. 5.

LOSSES

The average current per car for propulsion alone may be determined from speed time and power curves.* To this current should be added that used for lights, heaters and air compressor, to give the total current per car. The product of this total current per car multiplied by 600 (the voltage of the line), gives the power per car required at the direct-current bus-bars of the power house and sub-stations. This is the sum of the power at the car and the loss in the low-tension distributing system. This determination assumes

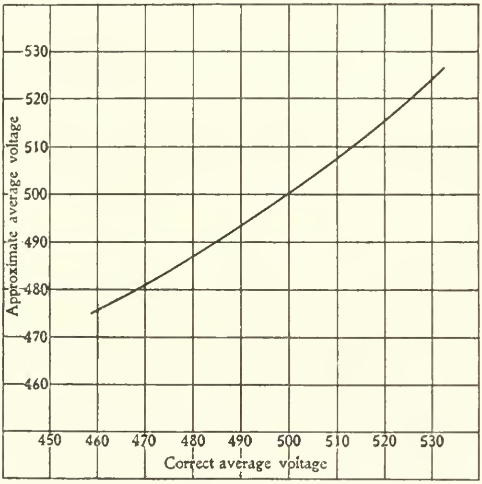


FIG. 6—CORRECTION CURVE FOR LESS THAN 600 VOLTS ON THE BUS-BARS

that the speed-time curve has been worked out for the proper average voltage at the car. On this assumption the line losses are equal to the product of the average current per car by the difference between station voltage and the average voltage at the car. For example, let 600 volts be the station pressure, V be the average pressure at the car, I the average current per car and L the low-tension distribution losses, then $L = I\ (600 - V)$.

If a close estimate of the line loss and power consumption is desired, the following method may be used: Lay out the train sheet,

*Method described in the May, 1906, issue of THE ELECTRIC JOURNAL, Vol. III, p. 247. See also article by Mr. W. S. Valentine on "Electric Train Performances" in the February, 1908, issue.

Fig. 4, on a large scale. Follow a local car through a round trip, calculating the drop at that car for a large number of points along the line and taking into consideration the variations in current at the individual cars as shown by the speed-time and power curves. Plot the values thus found on a time base and from the resulting curve obtain the average drop. Then the average voltage at the car is the difference between the station voltage and the average drop. It will probably be found that the average voltage so determined is somewhat different from the voltage at which the speed-time and power curves were originally calculated, so that this derived voltage is really only a first approximation to which a correction must be applied. The effect of such a difference is that an increased average voltage gives a lower average current, which tends to decrease the average drop and give still higher average voltage. Hence if the determined average voltage is higher than that assumed for figuring the speed-time and power curves, it is known that the correct average value is somewhat higher than either. The correction necessary may be found from Figs. 6 and 7. These curves are based on the use of a 40-ton car with a quadruple equipment of 75 hp motors, operating at schedule speeds from 28 to 32 miles per hour. Such service is fairly representative of a large class of interurban roads. Fig. 6 is given for roads maintaining not over 600 volts on the station bus-bars, and having sub-stations spaced well apart. Fig. 7 is given for roads with more frequent service, which maintain from 600 to 625 volts on the station bus-bars and have sub-stations fairly close together.

Having made the first approximation of average voltage, a corrected average voltage may be obtained from Fig. 6 or 7. The difference between the station and the average voltage gives the average drop. The product of the average drop and average current per car gives the loss per car in the low-tension distribution system.

Another method of estimating this loss is sometimes used. The train sheet is made up on a large scale and used to calculate the total losses in the low-tension distribution system by means of current and resistance. Each car may be considered as taking a constant current equal in value to the "square root of the mean square" current per car. The square root mean square current per car is used instead of the average current per car because the line loss at any particular instant is proportional to the square of the current flowing. The current in any section of the system at any time is found

by referring to the train sheet and considering the positions of all the cars at that time in connection with the locations of the feeding points.

Taking, for example, the nine mile section between the power house and sub-station No. 2, in Fig. 4, at 12:50 p. m. One car is on this section at a point 3.2 miles from the power house and 5.8 miles from sub-station No. 2. Assume that square root of the mean square current per car is 260 amperes. Then $5.8 \div 9 \times 260 = 167.5$ amperes are fed direct from the power house to this car. Reference

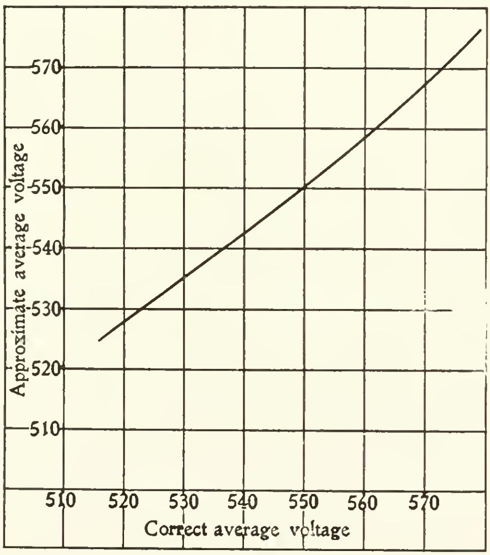


FIG. 7—CORRECTION CURVE FOR LESS THAN 625 VOLTS ON THE BUS-BARS

to page — shows that the resistance of trolleys, feeder and track on this section is 0.1 522 ohm per mile. Therefore the loss between the power house and this car is

$$\frac{(167.5)^2 \times 3.2 \times 0.1\,522}{1\,000} = 13.7 \text{ kw.}$$

Between sub-station No. 2 and the car the loss is

$$\frac{(92.5)^2 \times 5.8 \times 0.1\,522}{1\,000} = 7.56 \text{ kw.}$$

The losses on the other sections may be calculated in a similar manner and the sum of all the individual losses thus found will be

the total for the time, 12:50 p. m. Likewise, the losses for other times may be figured. These results plotted on a time base and integrated with a planimeter, give the average low-tension distribution losses for the system.*

DATA

1—Stranded copper cable, pounds per mile = area in cir. mils ÷ 62. For solid copper wire the constant is 62.6.

2—Rail area in sq. in. = pounds per yard ÷ 10.

3—Cir. mils copper equivalent for single track = 1 000 000 × lbs. per yard ÷ 44.

4—Cir. mils copper equivalent for third rail = 1 000 000 × lbs. per yard ÷ 64.

5—Drop per mile per 100 amp. = 5.5 volts for 1 000 000 cir. mils of copper.

Drops for other sizes are in inverse proportion to the areas.

6—Resistance of one mile of 70 lb. track rail is 0.07 ohm.

7—Volts drop = miles × hundreds of amperes × volts per mile per 100 amperes.

8—Aluminum—Pounds per mile = area in cir. mils ÷ 208.

9—Aluminum—Volts drop per mile per 100 amperes = 9 000 000 ÷ area in cir. mils.

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*Acknowledgment is due Mr. G. G. Watson for the valuable assistance which he rendered in checking curves and giving helpful suggestions in connection with this article.

METER AND RELAY CONNECTIONS—(Cont.)

SINGLE-PHASE CONNECTIONS

HAROLD W. BROWN

THE preceding articles of this series have referred to standard connections, and indicated how individual meters and relays are connected. This article deals mainly with combinations of instruments and methods of grouping them, and special connections for using instruments for special purposes.

USE OF INSTRUMENT TRANSFORMERS.

It would be possible to provide a separate series transformer for every meter and relay having a series circuit, and a separate shunt transformer for each shunt circuit, but the use of so many transformers would be expensive and they would often occupy too much space on the back of the switchboard. For these reasons, where several instruments are to be connected to the secondaries of shunt or series transformers on the same circuit, it is usually desirable to have more than one instrument connected to the secondary of each transformer. It would be possible to connect to a single transformer all the meters and relays that are to be operated by the same current or voltage, but both shunt and series transformers have poor regulation if too many instruments are connected to them.

Aside from the question of load, where several instruments are connected to the same shunt or series transformer, each instrument must be adapted to the same transformer ratio. If any instrument requires a transformer ratio different from that adapted to the other instruments, it must be connected to a separate transformer.

Series Transformers—The number of instruments that may be connected to a series transformer depends on the design of the transformer itself, the impedance of the instruments and the accuracy that is required of them at light load. With so many variable quantities it is not possible to adopt any universal rule, but it is customary to have not over three meters on each series transformer. If it is necessary that the readings on any meter be very accurate at light load, the meter should have its own series transformer. For example, an integrating wattmeter may be measuring the energy bought or sold, and even at light load an error in the measurement may represent a cost greater than the cost of an extra series trans-

former. On this account separate series transformers are often provided for integrating meters. If series transformers are used with a relay or trip coil they should not be used with meters, unless the drop through the relay or trip coil is so small as not to affect unduly the indications on the meters at light load.

Shunt Transformers—Shunt transformers have very nearly a true ratio at normal loads, but if the volt-amperes required greatly exceed the rated volt-ampere capacity of the transformer, the secondary voltage becomes too small. The number of instruments that may be placed on one shunt transformer depends on the volt-amperes that each instrument takes, the rated capacity of the transformer and the accuracy required. The voltage circuits of most meters do not take more than ten volt-amperes per phase, and shunt transformers for instruments ordinarily have a capacity of 50 volt-amperes or more, so that in general the voltage circuits of five meters may be connected to the same shunt transformer without seriously affecting the transformer ratio, In exceptional cases the number of meters should be less than five. Synchroscopes and automatic synchronizers require a transformer on each circuit that is to be synchronized.* These instruments may be connected to the shunt transformers that are used with meters, unless an excessive overload is thus put on the transformers. Some overload is permissible, because synchronizing apparatus should be connected in circuit only at the time of synchronizing; thus the error in transformer ratio, and the heating of the transformer are of short duration. The magnetic vane type synchroscope requires ten volt-amperes, the motor type requires 200 volt-amperes, and the automatic synchronizer requires 500 volt-amperes, in each of the synchronizing circuits.

SINGLE-PHASE CONNECTIONS.

In the meter and relay connections for single-phase circuits shown in the following pages, the load on the transformers is not excessive in any case illustrated, if ordinary meter transformers are used. In some cases the number of meters could be increased without trouble resulting. Three kinds of single-phase circuits are considered: *single-phase two-wire* circuits, *single-phase three-wire* circuits, and the *monocyclic* or *teaser* system.

The small arrows in the diagrams show the directions of the

*See preceding article on "Apparatus for Synchronizing," in the JOURNAL for Sept. 1908, p. 530.

currents in the meters, in accordance with conventions stated in previous papers in this series.† The meters are shown in groups to illustrate various possible methods of combining them, and to indicate the right order of connections to make the currents flow in the right directions in the various currents. It is customary to ground the secondaries of shunt and series transformers, as indicated in some of the diagrams.‡

Single-Phase Two-Wire Circuit—Grouping—A group of meters is shown in Fig. 1 suitable for a feeder or machine circuit, or for bus-bars. Only the integrating wattmeter is on a separate series transformer; the power-factor meter, indicating wattmeter, and ammeter are on another series transformer. All the instruments having voltage connections, except the static ground detectors, are connected to the same shunt transformer. Each side of the static ground detector is connected in series with a condenser, from one line to ground. These condensers may be slipped over the line wire, or may be mounted separately; in either case the line wire is not an essential part of the condenser surface.

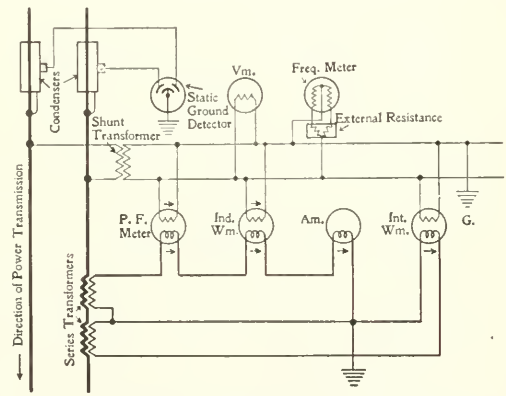


FIG. 1—GROUP OF METERS ON A SINGLE-PHASE CIRCUIT
Rear view.

Groups for Generators, Bus-Bars and Feeders—Of the three groups of meters shown in Fig. 2, the group at the left is suitable for a generator circuit, the one in the middle for the bus-bars, and the one at the right for a feeder circuit. It is obvious that the left hand group should be repeated for each additional generator, and the one at the right for each additional feeder. Only one group such as shown in the middle is necessary on a switchboard having

†See article on "Meter and Relay Connections" in the JOURNAL for May, July, August and September, 1908, and on "Vector Diagrams Applied to Polyphase Connections," June, 1908.

‡All of the foregoing references to transformers apply as well to polyphase as to single-phase circuits.

but one set of bus-bars For simplicity the present diagram shows only one series transformer for each group; if series transformers are added, protective relays, and graphic recording, integrating and other meters may be added on the various circuits as required.

The series transformer on the generator circuit sends current through the power-factor meter, wattmeter and ammeter on this circuit. The shunt transformer supplies the voltage circuit of the power-factor meter and wattmeter, and during synchronizing it also provides the e.m.f. for the upper (incoming) circuit of the synchroscope and the corresponding circuit of the synchronizing

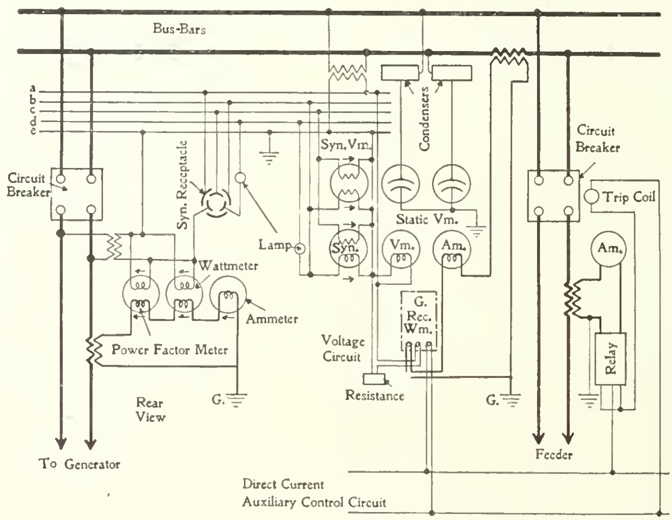


FIG. 2—GROUP OF METERS ON GENERATOR CIRCUIT, ON BUS-BARS AND ON FEEDER

a—to bus-bar transformer; *b*—to synchroscope, running circuit; *c*—to synchroscope, incoming circuit; *d*—lamp circuit; *e*—common transformer circuit. Rear view.

voltmeter Both the synchronizing voltmeter and the synchroscope have other circuits connected to the bus-bar transformer. The deflection of the voltmeter is due to the difference of the two e.m.f.'s, and the scale indicates the percentage that the voltage of the incoming circuit is high or low. The series transformer on the bus-bars sends its current through the bus-bar ammeter and the graphic recording wattmeter. The bus-bar shunt transformer is connected to the bus-bar voltmeter and graphic recording wattmeter, and during synchronizing to the lower (running) circuits of the synchroscope and synchronizing voltmeter.

The static voltmeters shown here are used instead of the ground detector shown in Fig. 1, when it is desirable to know the voltage of each line to ground independent of the voltage of the other line. The condensers are the same as those used with the ground detector, but in this case are shown connected to the bus-bars but not slipped over them.

An ammeter and an overload, inverse time element relay are connected to the feeder series transformer. The relay operates the trip coil by means of an auxiliary direct-current circuit. The same auxiliary circuit is used to operate the graphic recording wattmeter.

If connections are made to the meters and relays through a cable, they are represented as indicated in Fig. 3. The cable is represented by a dotted line and the opening at the end of the cable by

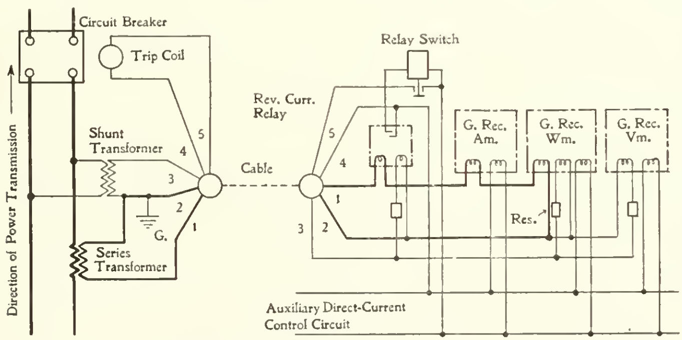


FIG. 3—GRAPHIC METERS AND RELAY CONNECTED THROUGH A CABLE TO A SHUNT AND SERIES TRANSFORMER AND TRIP COIL
Rear view.

a circle. Each wire of the cable is designated by a number—the number being the same wherever this wire is brought out of the cable. This diagram shows three graphic recording meters, a reverse-current relay, and a relay switch. The impedance of the current circuit of the reverse-current relay is no greater than that of some meters, so that the relay may be connected in series with the current circuit of the other meters. The direct-current auxiliary circuit operates the graphic meters, the relay switch and, through the relay switch, the circuit breaker trip coil. Fig. 3 shows a cable used in connection with a two-wire circuit. It may be used as well on other single and polyphase circuits.

Special Use of Polyphase Wattmeter—In Fig. 4 a polyphase wattmeter is shown connected to a single-phase circuit. This is an

unusual connection, but is convenient in an emergency. If the two voltage circuits are connected in series and the current circuits in parallel the meter indicates one-half the actual power transmitted. If the voltage circuits are in parallel and the current circuits in se-

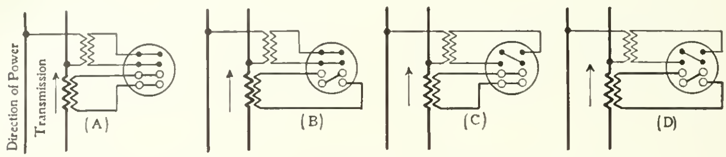


FIG. 4—POLYPHASE WATTMETER ON SINGLE-PHASE CIRCUIT

Rear view. *A*—Voltage circuits in parallel, current circuits in parallel indicates actual watts. *B*—Voltage circuits in parallel, current circuits in series, indicate twice actual watts. *C*—Voltage circuits in series, current circuits in parallel, indicates one-half actual watts. *D*—Voltage circuits in series, current circuits in series indicates actual watts.

ries, the meter indicates twice the actual power transmitted. If the voltage and current circuits are both in parallel or both in series actual power is indicated.

Single-Phase Three-Wire Circuits—Group Without Plugs—In Fig. 5 several meters are shown connected to a single-phase three-wire circuit. Two meters of each kind (except the frequency meter) are shown—one connected to each side of the circuit. Since

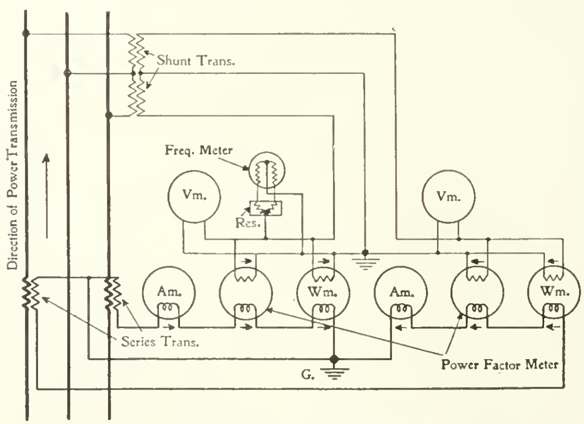


FIG. 5—SINGLE-PHASE, THREE-WIRE SYSTEM
Rear view. Separate meters on the two sides.

the frequency is the same on each side, only one frequency meter is required. It is possible by means of plugs to use the same meters in making measurements on the two sides of the circuit, but it is preferable to have one complete set of meters on each side, as

here represented, first, since if the same meter is used for two circuits it cannot indicate continuously the condition of each circuit, and second, because there is a possibility of making a poor contact in shifting back and forth from one circuit to the other

Group With Use of Plugs—Fig 6 is similar to Fig 5, but has only one set of meters for the two sides of the circuit. When the four-point voltmeter plug is inserted in the left hand side of the voltmeter receptacle it connects all the e.m.f. circuits of the meters to the shunt transformers on the left hand circuit; and when an ammeter plug is placed in the left hand ammeter receptacle it connects all the current circuits of the meters to the left hand series transformer. With this arrangement of plugs all meter indications refer to the left circuit; with the plugs in the right hand positions the meter indications refer to the right hand circuit. With ammeter plugs in both ammeter receptacles, and the voltmeter in either position, the ammeter indicates the numerical sum of the currents,* the power-factor meter indicates the mean power-factor of the power transmitted on the two sides of the circuit, and the wattmeter indicates the total power transmitted. If the two e.m.f.'s are not equal, a small error is introduced in the wattmeter reading.

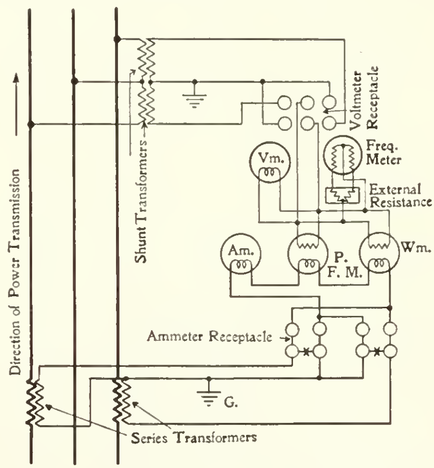


FIG. 6—SINGLE-PHASE THREE-WIRE SYSTEM USING ONLY ONE METER OF EACH KIND

Rear view.

Fig. 7 represents either a single-phase wattmeter or a single-phase power-factor meter connected to a single-phase three-wire circuit. Assuming a wattmeter, the current in the current circuit is the numerical sum of the outside currents, and the e.m.f. across the voltage circuit is the e.m.f. from one outside line to the middle line. If

*See discussion of Figs. 7 and 8 in article on "Vector Diagrams Applied to Polyphase Connections" in the JOURNAL for June, 1908. This connection would be used for determining the equivalent total current at an e.m.f. equal to that between the middle line and one side line of the circuit. It does not indicate the current flowing in the middle line.

the two e.m.f.'s are not equal, an error is introduced, but usually this error is negligible. The shunt transformer may be connected to the two outside lines instead of being connected to one outside and the middle line, provided the transformer and wattmeter are made for that e.m.f. In that case the indication is twice the actual power and no error is introduced unless the e.m.f.'s and the currents are both unequal, and even then the error is very small.

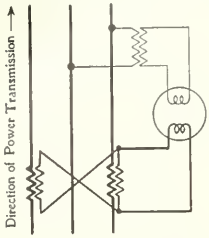


FIG. 7—SINGLE-PHASE WATTMETER OR POWER-FACTOR METER ON SINGLE-PHASE THREE-WIRE CIRCUIT
Rear view.

A power-factor meter connected as in Fig. 7 indicates the power-factor of the two currents. If the two have not the same power-factor, the meter indicates the mean power-factor of the total power transmitted. The e.m.f. circuit should be connected from one side to the middle as shown, or between outside lines, depending on the e.m.f. to which the transformer and the meter are adapted.

Polyphase Instruments on Single-Phase, Three-Wire Circuits—A polyphase wattmeter is shown connected to a single-phase three-wire circuit in Fig. 8. The left hand circuit of the wattmeter measures the power transmitted between *C* and *B*, and the right hand circuit that between *A* and *B*.

Fig. 9 shows a polyphase overload relay, and Figs. 10 and 11 two single-phase overload inverse time limit relays, protecting a single-phase three-wire circuit. Fig. 10 has a shunt trip, and Fig. 11 a series trip relay.

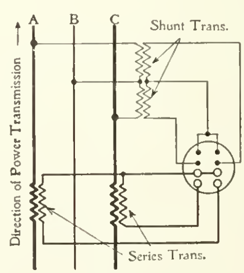


FIG. 8—POLYPHASE WATTMETER CONNECTED TO SINGLE-PHASE THREE-WIRE SYSTEM
Rear view.

Meters for Measuring Unbalancing—In Fig. 12 a voltmeter, ammeter and wattmeter are connected to a single-phase three-wire circuit in such a way as to indicate the unbalancing of the two sides of the circuit. The voltmeter indicates the difference between the e.m.f. across the left hand circuit (*A* and *B*) and that across the right hand circuit (*C* and *B*). The ammeter indicates the numerical difference between the currents in *A* and *C*—that is, it indicates the current in *B*. The wattmeter indicates the difference between the power transmitted by the left hand circuit and that by the right hand circuit. When the watt-

meter deflects to the left of zero it indicates that more power is being transmitted over to the left hand than over the right hand circuit; when it deflects to the right, it indicates that more power is being transmitted over the right hand circuit.

Monocyclic or Teaser System—The teaser system may be considered as having a single-phase two-wire circuit with a small third wire whose e.m.f. is out of phase with the e.m.f.'s of the two main wires. Single-phase power is transmitted over two wires (see *A* and *C* in Fig. 8, which, in the present case, is assumed to be transmitting three-phase power over the three wires). This system is used where the three-phase power required is small compared with the single-phase, or where it is used only intermittently. Fig. 8 now represents a polyphase wattmeter measuring the total single-phase and polyphase power transmitted by such a system.

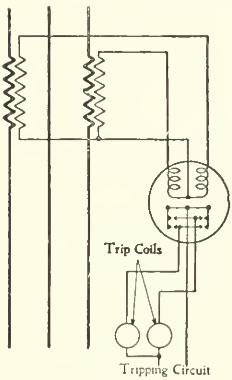


FIG. 9—POLYPHASE OVERLOAD RELAY CONNECTED TO SINGLE-PHASE THREE-WIRE CIRCUIT
Rear view.

In Fig. 13 a single-phase power-factor meter is connected to a monocyclic system, so as to measure the power-factor of the single-phase and polyphase power. With single-phase power transmitted over *A* and *C*, and an equal amount of three-phase power over *A*, *B* and *C*, the single-phase power has about twice as much weight as the three-phase in determining the power-factor that is indicated. This introduces a theoretical error in indicating the mean power-factor, but the error is usually so small as to be negligible.

To measure only three-phase current, power and power-factor on a teaser system, an ammeter, wattmeter and power-factor meter may be connected as in Fig. 14. The ammeter measures the current in line *B*. This method of connecting shunt transformers produces an e.m.f. on the wattmeter and power-factor meter, that is 1.73 times the e.m.f. across the secondary of one transformer. At 100 percent power-factor, this e.m.f. is in phase with the current in *B*. This makes the wattmeter indicate the total power

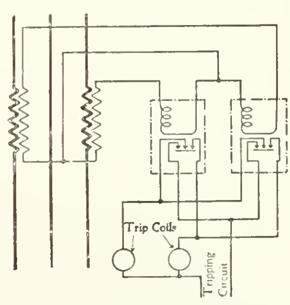


FIG. 10—TWO SINGLE-PHASE INVERSE TIME LIMIT SHUNT TRIP RELAYS CONNECTED TO SINGLE-PHASE THREE-WIRE SYSTEM
Rear view.

transmitted. If the current of line *B* is not equal to the three-phase currents in lines *A* and *C*, or if the e.m.f.'s between *B* and the other lines are not equal to that between *A* and *C*, an error will be introduced due to the unbalancing. The power-factor meter indicates the power-factor of the current in *B*, which is the same as that of the other three-phase currents if they are balanced.

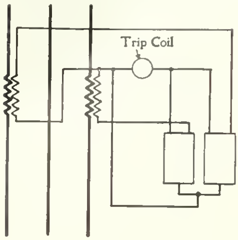


FIG. 11—SAME AS FIG. 10, EXCEPT RELAY IS SERIES TRIPPING
Rear view.

IN GENERAL

All the foregoing diagrams show meter connections suitable for high tension circuits. In most cases if the line e.m.f. is not over 125 volts, the *shunt* transformers may be omitted. In Figs. 12 and 14, however, at least one shunt transformer is required even on low voltage circuits. *Series* transformers are always required on very high voltages for the purpose of insulation. They are also required on low voltage circuits, unless the line current is so small that it may be passed directly through the meters.

In several cases a common return line is used between meters and transformers, to simplify the wiring. It usually makes little difference which secondary terminal of a series transformer is connected to the common return, if other meter connections are made to correspond; but if the meters are very far from the transformers, the line drop may be appreciable, and in that case it may frequently be reduced by choosing connections so that the current in the common return line is small. These diagrams show connections for a minimum current in the common return line wherever nothing would be gained by any different connections.

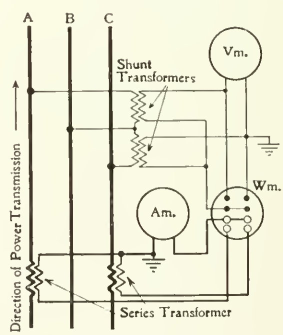


FIG. 12—METERS CONNECTED TO SINGLE-PHASE THREE-WIRE SYSTEM TO INDICATE THE UNBALANCING OF CURRENT, VOLTAGE AND POWER
Rear view.

An auxiliary control circuit is shown in several of the diagrams. This is usually a direct-current circuit, as is indicated, but an alternating-current circuit may be used if the apparatus is adapted to it.

Only a few graphic recording meters are shown in the diagrams, but whenever indicating meters are shown, they may be replaced by graphic recording meters. Meters of this type with indicating dials and pointers are obtainable; when thus arranged they serve the double purpose of indicating and making a permanent record of their measurements.

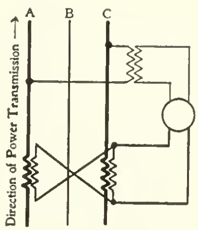


FIG. 13—SINGLE-PHASE POWER-FACTOR METER INDICATING POWER-FACTOR OF TOTAL POWER ON MONOCYCLIC SYSTEM

Rear view.

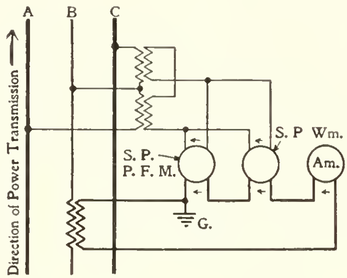


FIG. 14—METERS MEASURING THREE-PHASE POWER, POWER-FACTOR AND CURRENT ON MONOCYCLIC SYSTEM

Rear view.

Each of these diagrams shows one way of making connections, but in every case there are several other correct ways in which they may be made. The purpose of the diagrams is to suggest principles and illustrate methods, rather than to indicate every possible method of grouping meters and relays.

EXPERIENCE ON THE ROAD

USE OF AUTO-TRANSFORMERS IN CHANGING POLYPHASE CURRENTS

M. H. RODDA

A simple and economical method of changing the number of phases in a polyphase system is afforded by the use of auto-transformers. The application of this method, however, is not so general as is the case with ordinary transformers.

If it is desired to supply three-phase power at 2 200 volts from a two-phase, 2 200 volt generating station, two auto-transformers may be used provided the two-phase generators are of the type with no connection between the two armature windings. Two ordinary transformers of the two coil type, having a ratio of one to one, can of course be used for this purpose regardless of the type of generator windings. The method of connecting the auto-transformers is shown in Fig. 1. This method is efficient and much less expensive

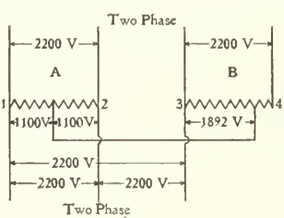


FIG. 1

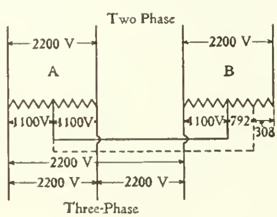


FIG. 2

than the use of two coil transformers. At the middle point of transformer *A*, a connection is made to an 86 percent tap on transformer *B*. This interconnects the two-phase windings so that three-phase power may be obtained by connecting to terminals *1*, *2* and *3*.

If the generators supplying the two-phase current are of the revolving field type with their windings connected at the middle point or if they are of the stationary field type having armature windings similar to a rotary converter or if a rotary converter is supplying the current, the auto-transformers will not serve, as in this case the connections will be as shown in Fig. 2 and there will be no potential difference between the middle points of transformers *A* and *B*. If the connection indicated by dotted lines, from the middle of transformer *A* to the 86 percent tap on transformer *B* be made, 36 percent of the winding of transformer *B* will be short-circuited and cause trouble.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly. If a personal reply is desired in advance of publication a stamped return envelope should be enclosed.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

150—WORKING TEMPERATURE OF TRANSFORMERS—In oil-insulated, water-cooled transformers for high tension work, what is the usual maximum allowable working temperature of the oil, and at what temperature may deterioration of the insulation be expected to commence? P. L. S.

The allowable working temperature of transformer oil varies with different kinds of oil. A sediment is thrown down and deposits on different parts of the transformer when part or all of the oil is raised to a sufficient temperature. A local hot spot may start this sedimentation even though the average temperature of the oil may be moderate. Modern well-designed transformers are free from local spots, due to the liberal provision of ventilating ducts, so that the average oil temperature as indicated by the thermometer near the oil level will be a guide for the operator in noting the temperatures of his transformers. A continued temperature of 80 degrees C. (176 degrees F.) should ordinarily not be exceeded. Water-cooled transformers are usually provided with electric contacts in their thermometers, which will operate an alarm should the temperature exceed approximately 85 degrees. A description of such an arrangement is given in the article by Mr. L. T. Peck on "The Great Falls Power Plant of the Southern Power Company" in the JOURNAL for December, 1907. K. C. R.

151—TRANSFORMER COOLING COILS—Is brass used instead of iron for the cooling coils of transformers because of the liability of corrosion of the iron by the water, or by the oil; or is it to facilitate the transfer of heat from the oil to the water? P. L. S.

Iron coils have been found to be subject to corrosion due to the action of the water. The oil, however, would have no more action on the iron than on the brass. Brass has a greater heat conductivity than iron and hence it is much more effective for cooling coils.

152—NO-LOAD POWER-FACTOR OF TRANSFORMERS—A 40-ampere, 2 000-volt polyphase, integrating wattmeter is properly connected to a circuit on which are transformers which, when loaded to their rated capacity, give a load of 60 kw. When there is no load on the transformers, (*i. e.*, the circuit supplying only the transformer iron loss), will one side of the wattmeter have a tendency to rotate in the reverse direction as it would with an induction motor load with less than 50 percent power-factor? F. C.

There will be a tendency for one element of the polyphase wattmeter to rotate backward if the power-factor is less than 50 percent. However, without knowing the frequency, and the characteristics of the transformer, it is impossible to state definitely whether the power-factor would be above or below 50 percent. Without doubt, a 25-cycle transformer would have a no-load power-factor of less than 50 percent. The power-factor of 60-cycle transformers at no-load may be from 40 to 70 percent, two transformers built on the same specifications not necessarily having the same power-factor. Because of the better magnetic qualities of the iron used in the present designs, it is worked at a higher induction than formerly. The effect is to give a lower no-load power-factor, the charging current remaining practically the same, while the iron loss is reduced. E. C. S.

153—COMMUTATOR MICA—Can flexible micanite plate be used between the head of the commutator shell and the bars, and also between the ring and bars on direct-current machines of from one-half to 250 hp capacity, the operating voltage being 240 volts? It was not thought to be advisable to use this material between the commutator bars. G. A. F.

In commutator construction it is not advisable to use flexible mica where it will be under pressure, *e. g.*, under the V-rings and between the bars. Flexible mica is usually constructed by sticking together small pieces of mica in overlapped layers, using as a bond a material, such as varnish, which dries slowly. One or both sides are then covered with thin paper to prevent the mica from flaking off. If such a material is used under pressure it will be found to "give," especially when it becomes hot and when subjected to the centrifugal action due to the rapid rotation of the armature. The immediate result is "high bars." Also, the heat may be sufficient to carbonize the paper, the shrinkage resulting in looseness of the bars. Micanite can be used in places where the centrifugal force can have no harmful effect; *e. g.*, around the iron bushing inside the commutator.

154—RAIL USED AS COMMON RETURN FOR TWO DIRECT-CURRENT CIRCUITS OF DIFFERENT VOLTAGE—Can we use the rail as a common return for two circuits, one of 250 volts supplying mining machines, pumps, etc., and the other of 500 volts supplying a railway circuit? The loads are both very fluctuating. C. F. B.

The negative side of each generator may be connected to the rail using it as a common return for the two circuits without difficulty. The precaution should be observed of bonding the rails carefully so that their conductivity may be as good as possible. See also Question and Answer No. 81 in the June issue.

155—SHORT CIRCUIT ON TRANSMISSION LINE—If a short circuit should occur on one phase of a transmission line to which power is being supplied from a 1 000 kw, 6 600-volt, 25-cycle, three-phase turbo-generator operating in parallel with two 750 kw generators direct-connecter to reciprocating engines, motor-driven exciters being used, what effect would this short circuit have on the field of the turbo-generator if the voltage were to drop so low that the motor driving the exciters pulled out and shut down the plant? What effect would there be if the voltage dropped but immediately picked up before the exciter motor pulled out of step, thus avoiding the shut-down? In either case would there be a potential generated as a result of the short-circuit tending to ground or short-circuit the field of the turbo-generator? If so, please explain how it would occur. E. C.

In general the only effect on the field which might be expected from a short circuit on a power transmission system, such as you have described would probably be a sudden fluctuation of voltage in the circuit as a result of the short circuit of one phase. This sudden surge might be found to cause a voltage "kick" in the fields of the generators as a result of a transformer action between the armature and field windings. If the generators were direct-connected to the line this kick would be greater than if there were transformers intervening, as the latter would tend to retard or choke the sudden surge. If the engine-driven alternators have solid field iron the rise of voltage will not be as pronounced as though the fields were constructed with laminating iron, as in the latter case there would not be as great a damping or retarding effect. The turbo-generator probably has solid field pieces. Considering the foregoing, it will be seen that an intermittent short-circuit or intermittent ground would be apt to have a more disastrous effect in causing continued

surges than a steady ground or short circuit; the latter condition would probably result in immediately causing the circuit breakers to open the circuit. In this connection see the article by Mr. R. P. Jackson on "The Protection of Electrical Circuits," in the JOURNAL for February, 1908, p. 85. The effect of a short circuit of such short duration or small intensity as not to cause the exciter motor to pull out of step would probably not have any serious effect. The insulation of electric apparatus is now made to withstand even quite serious surges and rises of voltage without injury.

W. L. W.

156—RATING OF SIX-PHASE ROTARY CONVERTER—With two rotary converters built on similar frames, having same kilowatt rating, speed, voltage and frequency, but one rotary being six-phase and the other three-phase, how would the temperatures and efficiencies of the six-phase converter compare with the three-phase? C. I. Y.

This may be considered in two ways, either that the rotary converter has been designed specifically for six-phase service or that it has been designed for three-phase service and applied to six-phase service without other change than the addition of the necessary tape, collector rings, and brushes. Under the first assumption there will be no difference in the average heating or efficiency, but less copper will be required in the armature of the six-phase machine in the ratio of 0.56 to 0.26. The six-phase rotary converter, although having the same average copper loss, will have the loss more evenly distributed. In any rotary converter, the current in the tap coils is greater than in the coils midway between the tap coils. This difference is considerably less in the six-phase machine than in the three-phase. Under the second assumption, the six-phase rotary converter will have less copper loss in the ratio 0.56 to 0.26, and the heating of the end connections will be reduced, although not in the same ration due to the influence of the heat in the armature core. The reduction in copper loss will improve the efficiency, although the gain will be small since the coper loss is only a small proportion of the total losses. This is particularly true in sixty-cycle rotary converters. Probably the greatest advantage of the six-phase over the three-phase machine is in the more uniform distribution of armature copper loss. F. D. N.

157—SYNCHRONIZING HYDRAULIC AND STEAM PLANTS—It is desired to operate a three-phase steam plant in parallel with a water power plant. Heretofore the two stations have been operated independently on two sets of bus-bars through double-throw switches. What is the method of determining whether the generators are phased for parallel operation? D. H.

Designating the three bus-bars of the steam plant as A_1, A_2 and A_3 and those of the hydraulic plant as B_1, B_2 and B_3 insert incandescent lamps between A_1 and B_1, between A_2 and B_2, and between A_3 and B_3. If, with the lamps so arranged, they light up together so that any fluctuations show on the three lamps simultaneously, the bus-bars may be connected. A_1 should then be connected to B_1, etc. If the lamps show fluctuations in the light irregularly, the order of connection will have to be changed and a combination obtained by means of the lamps which will cause them to operate together, thus indicating that the proper phases are selected for parallel operation. After the proper connections have once been determined it will be necessary to synchronize only on one phase of each set of bus-bars. The number of lamps in series between A_1 and B_1, etc., should, of course, be governed by the bus-bar voltage. P. M. L.

158—IN AN ALTERNATING-CURRENT CONTROLLER used with a two-phase motor, the circuit is broken on one contact before making the next contact. Please explain this. J. R.

This probably refers to the type of controller using an auto-transformer having successive taps connected to the controller contacts. One of the two following methods is employed in the controller in moving from one

contact to the next—either one contact is broken before the next is made, or a double finger is used having a "preventive" resistance between the two parts of the finger. One or the other of these arrangements is necessary in order that the section of the auto-transformer included between the two contacts may not be short-circuited during the operation of moving from one to the other. The former method is ordinarily employed for the controllers of smaller capacity, where the total amount of energy to be interrupted is not large. E. E. L.

159—Wattmeter Reversal on Unbalanced Load—We have a four-wire three-phase system with an out-of-balance lighting load of 25 kw connected between one phase of the line and the neutral, which lowers the voltage eight percent. Would this condition of load cause one of the watt meters on another consumer's plant to run backward, this consumer having three single-phase meters to measure the power consumed by a three-phase induction motor? E. W. C.

If the unbalanced lighting load is of sufficient capacity, compared with that of the generator and the customer's motor, to appreciably unbalance the line voltage, say eight or ten percent, the motor will act as a transformer, taking energy from the high voltage phases and delivering it back to the low voltage phase. A wattmeter in this place would then run backward. This transformer action is more liable to take place on light load, as with a heavy load the line loss tends to reduce unbalacing of the voltages. This trouble will be obviated by the use of a polyphase meter which will record the arithmetical sum of the power in all phases. W. B.

160—V-Connected Transformers—I would be pleased to know what the transformer action, phase-relation and voltage would be in the following case; also your method of solving the problem. In a three-phase delta-connected set of three transformers the high tension insulation of one transformer became punctured. After disconnecting the damaged transformer on the high-tension side only, the connections were as below. F. J. B.

The connections which you have shown indicate that the three-phase bank of transformers was "half-tapped" to give reduced voltage for starting, the taps from the two transformers, which are half-tapped, of course being moved to the outside terminals of these transformers in the running position. By disconnecting the third transformer on the high tension side, the other two transformers are left in "open-delta," *i. e.*, V-connected. The low-tension side of the damaged transformer should also be disconnected. The two remaining transformers will then be connected in open-delta to correspond with the high-tension connections. The effect of omitting the third transformer is to reduce the capacity of the set to about 60 percent of the capacity with three transformers operating. The effect of leaving the low-tension side of the third transformer in circuit with the high-tension side disconnected is to maintain the iron loss in this transformer without its doing any work, *i. e.*, the capacity of the set is no less with the low tension side disconnected than with it in circuit, when the high tension side is disconnected. In this connection note Questions 21 and 91 in the Journal for February and June, 1908, respectively. K. C. R.

Note.—Attention has been called to a statement in the August issue in the article by Mr. J. S. S. Cooper on "Direct-Current Turbo-Generators," page 434, which may give a wrong impression, as follows: "It may be seen that the brushes are not quite in the radial position," etc. This should be: "It may be seen that the brushes are not quite in their right position, that is not quite radial."

THE

ELECTRIC JOURNAL

VOL. V. NOVEMBER, 1908 NO. 11

Losses in Single-Phase Railway Circuits

It is fortunate that the useful outcome of the tests which Mr. Copley reports in the article on "Constants of Single-Phase Railway Circuits," in this issue of the JOURNAL, can be put in such simple form as in the last paragraph in which are presented the essential constants of single-phase railway circuits. It is not uncommon to find a case in which theory is complex and physical constants are erratic, and yet the practical result is simple and effective. The induction motor is an example. It is susceptible of theoretical mathematical treatment of such profound, and to many persons repulsive, appearance that it would scarcely seem possible that the practical outcome should be the simplest type of operating apparatus.

Again, when one considers the elements which enter into the measurement of power in an alternating-current circuit, volts, amperes, changing phase relations and wave forms, and the proper integration of varying instantaneous values, and when it is further remembered that for the comparatively simple requirement of direct-current measurement various types of chemical and commutating meters have been devised which involve serious practical limitations and handicaps, it is surprising to find that remarkably accurate results can be obtained by the rotation of a simple aluminum disc in a magnetic field. The little disc is continuously solving problems which sorely tax the student with his formulae and vector diagrams.

The flow of alternating-current through an ordinary circuit containing resistance and inductance has been considered in several articles in the JORNAL, and constants have been given for circuits consisting of parallel copper wires. Substantially similar conditions are found in the trolley side of the railway circuit. The track and earth return, however, present quite different conditions for several reasons. The rails are of iron, they are not cylindrical, but are of irregular form, the earth conductor is indefinite in extent, its resistance is not constant and uniform, and the laws governing the division of current between the magnetic rails and the indefinite earth are not obvious and simple. The rails offer a higher effective

resistance to alternating than to direct currents; hence the flow of a given current results in a greater loss of power and requires a higher voltage. The rail loss although a matter of great importance in direct-current service requiring heavy currents is of minor consequence with relatively small alternating currents. A car requiring 100 kilowatts will take about 200 amperes at 500 volts with direct current or ten amperes at 10 000 volts with alternating current. With equal rail resistances the loss in the second case is only a quarter of one percent of that in the 500 volt circuit. The rail loss in this case is about one percent per mile of track for direct-current and one percent for something over a hundred miles of track for alternating current allowing for increased loss with alternating-current and assuming in both cases that all return current flows in the rails.

Probably the most notable feature of the measurements is the large proportion of alternating current, sixty percent in a single track road, which leaves the track and returns by earth. This is largely an inductive effect. The conditions may be illustrated by a simple supposition. If the track be insulated from earth and an insulated wire be buried at a depth of several yards under the track, then if one end of the wire be connected to the track and a voltmeter be connected between the other end of the wire and the track at a distance of say a mile a considerable secondary voltage may be measured, resulting by induction from the current in the trolley and track as primary circuit. If the wire be connected to the track at each end a current will flow through it. The earth itself will obviously have a secondary voltage induced between it and the track, similar to that between the hypothetical wire and the track, and a current will flow through the earth if the track is not insulated. The practical effect is to lessen the part of the current which returns by the rails and increase that in the earth. As the track forms one side of the secondary circuit, and as the voltage induced depends upon the size of the conductors, it is not the same for single track and four track roads. Knowing from prior measurements on a single track road the proportion of track and earth currents and recognizing the effect of several trolley wires and tracks, I predicted a lesser earth current with a four track road and made a preliminary approximate calculation which gave about eighty percent rail current; subsequent measurements gave seventy-five percent. The effect of the shifting of current from the rails to the earth is to reduce the loss in the rails, thereby rendering of less consequence the difference in their effective resistance to alternating and to direct current.

Mr. Copley has had exceptional facilities for securing the data which he has given. Numerous practical difficulties were encountered and some of the measurements were of a difficult kind to make with a high degree of accuracy, as he has pointed out. Although the phenomena are complex and in some features somewhat surprising, yet they indicate no undue transmission losses, either in voltage or in power. Trolley wires and tracks have proved to be adequate for operating a very heavy train service over distances which would require many large substations and supplemental feeders if direct-current were employed.

CHAS. F. SCOTT

Varying The Voltage Ratio of Rotary Converters

Mr. Newbury's discussion on the split-pole rotary converter in this issue brings out one point which previous descriptions of this device have not sufficiently emphasized, viz., that this machine must depend, for variation in the ratio between alternating and direct-current voltage, entirely upon the introduction in its field form of harmonics of the same order as the phase of the generating system to which the machine is attached. For instance, in a three-phase system all changes in ratio must be those caused by the introduction into the field form of the converter of a third harmonic or multiple thereof. All harmonic fields of other orders are practically wiped out by circulating currents. Since nearly all generating systems are three-phase, it follows that change in ratio must be caused by the introduction of third harmonics into the converter fields.

This consideration indicates one marked superiority of the three-part pole machine over the two-part type. Both types arrive at practically the same results so far as changing the ratio is concerned, but in the latter type considerable circulating current must flow owing to the fact that the two-part field construction necessarily causes many harmonics other than the third to be introduced into the field form. The construction of the three-part pole machine on the other hand may be such that practically none but third harmonics need be introduced into the field form.

After all, the crux of this whole question is contained in Mr. Newbury's last paragraph. This device gains no new end and its only *raison d'etre* must be that it attains an old one with greater economy. That it does so has not been shown. Although its ingenuity is admitted; utility, not ingenuity, must be its final criterion.

P. M. LINCOLN

VOLTAGE VARIATION IN ROTARY CONVERTERS

F. D. NEWBURY

THE direct-current voltage of a rotary converter can be changed only by an initial change in the impressed alternating-current voltage or by an initial change in the shape of the magnetic field set up by the field windings of the converter. Various practical ways of utilizing the first of these methods have been in successful use for some time, notably:—reactance coils and variable field excitation, as in compound-wound rotary converters for railway work; taps from the lowering transformers or from separate regulating transformers, and the so-called induction regulators. More recently another method of obtaining variations of voltage on the direct-current side by changing the alternating-current voltage has been introduced. This method, first suggested by Mr. Chas. F. Scott, involves the use of a synchronous alternating-current booster mounted on the same shaft as the converter armature and connected, electrically, in series with it. Any change, then, in the booster voltage, either in amount or direction, results in a corresponding change in the alternating-current voltage impressed on the converter armature. The foregoing methods are all similar in that they employ means for varying the e.m.f. delivered to the collector rings of the converter. There has also been introduced recently a method of direct voltage variation based on the second of the two principles mentioned above, i. e., by a change in the shape of the magnetic field. This is the aptly-named "split-pole" method, in which each pole is split up into two or more sections and the field form varied by varying the excitation of the different sections. This method was first proposed by Mr. J. L. Woodbridge, and later modified by Mr. J. L. Burnham.

The present article will trace briefly the development of the methods of direct-current variation involving a change in the alternating-current voltage and will compare, more fully, the booster method as the latest and most promising of these methods, with the split-pole method.

REACTANCE AND VARIABLE EXCITATION

This method has been in use for so long a time that no extended explanation need be given. Briefly, the essential elements are reactance, either in the lowering transformers or in separate coils, and

series windings on the field poles of the rotary converter. With increase of load the converter excitation in a compound-wound converter increases, thereby causing the phase relation of the current to be "leading" with respect to the line voltage. This change in the phase relation of the current changes the phase relation of the reactance voltage with respect to the supply voltage, in such a way that the resultant voltage at the converter terminals is increased. The change in impressed alternating-current voltage causes a corresponding change in the direct-current voltage. The maximum range of voltage variation with this method is small—not over ten percent—and is obtained at the expense of a varying power-factor. The voltage variation is, however, inherently automatic and this feature makes it especially suitable for railway work in which the load fluctuations are large and rapid. The variable excitation could be obtained by varying the shunt field current by hand, but where non-automatic variation is desired, a greater voltage range is usually necessary so that this method is not feasible. It is practically limited to railway applications, but in this field it is entirely satisfactory, and is used to the exclusion of other methods.

VARIABLE VOLTAGE FROM TRANSFORMERS

In this method a number of taps are brought out from the lowering transformers and by means of a dial switch the tap for the voltage desired is connected to the converter terminals. This method is objectionable for several reasons:—the wiring is cumbersome; the dial switch is subject to rapid deterioration; if a large range of voltage is desired, the number of voltage steps are large; the method is not only inherently non-automatic, but can not easily be made automatic and is better suited for occasional adjustment of voltage of a fairly constant or slowly varying load than for cases where frequent adjustments are necessary.

INDUCTION REGULATORS

This method is the one in most general use at the present time in applications requiring a large range of voltage variation. The polyphase induction regulator is virtually a polyphase transformer in which the primary is movable relatively to the secondary. The primary circuit is in shunt, and the secondary circuit in series with the converter circuit. A constant voltage is induced in the secondary but its phase relation with respect to the line voltage is changed

by the rotation of the primary, the voltage variation being obtained by this change in phase. The change in voltage is secured without opening the circuit, so that there are no switch contacts involved; the change in voltage is continuous instead of in steps; and the method, while inherently non-automatic, can easily be made automatic if desired. The induction regulator thus overcomes the principal faults of the step-by-step method using transformer taps. The principal objections to this method are:—the complications introduced in the station wiring; the care and expense involved in the

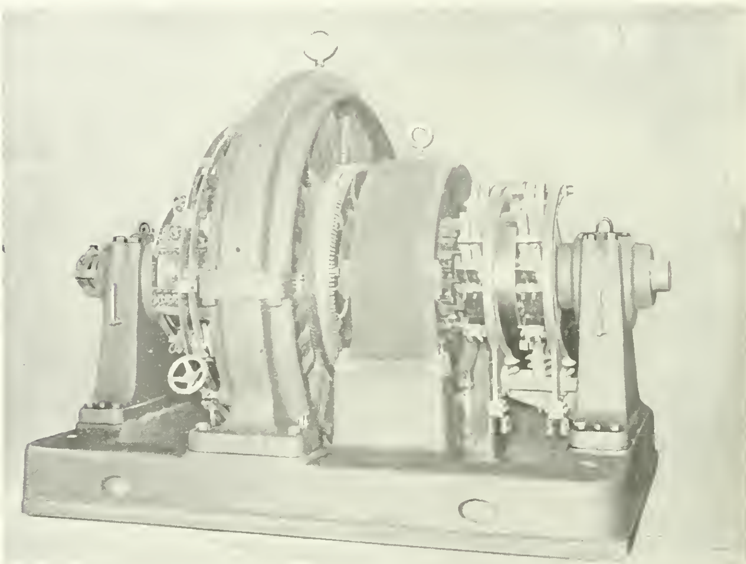


FIG. 1—500 KW, 25 CYCLE, 250 VOLT SYNCHRONOUS BOOSTER-CONVERTER SET WITH TWO SEPARATE FRAMES
Range 225 to 275 volts.

maintenance of separate pieces of apparatus, and in the case of city sub-stations, the extra floor space required.

THE SYNCHRONOUS BOOSTER

Just as the induction regulator overcomes the major shortcomings of the step-by-step method of voltage variation, the minor faults of the induction regulator are eliminated by the introduction of the booster-converter. This method involves the addition of an alternating-current generator of special characteristics to a standard rotary converter. The generator has the same number of poles as

the converter, and the two revolving parts are carried by the same shaft. The booster therefore generates a voltage of the same frequency and phase as the induced voltage of the converter and, by properly proportioning its parts, the wave shape of the booster may also be made the same as the wave shape of the converter voltage. The booster armature is connected in series with the converter armature so that the voltage delivered to the converter armature is the sum of the line voltage and the booster voltage. The delivered voltage is varied by varying the field current of the booster—in one direction to raise, and in the other direction to lower the converter volt-

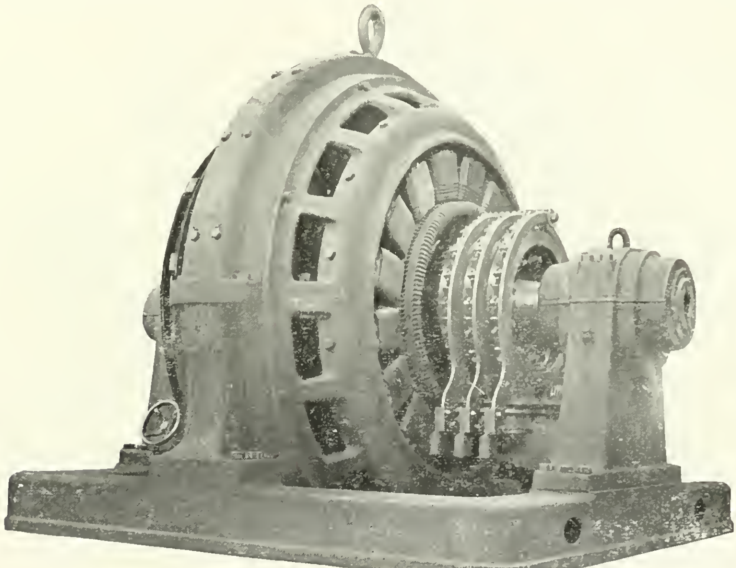


FIG. 2—1 000 KW, 25 CYCLE, 270 VOLT SYNCHRONOUS BOOSTER-CONVERTER SET
Range 230 to 310 volts. Slip ring end.

age. In its simplest form the booster armature is made the rotating element and is mounted on the shaft between the armature and collector rings of the converter. The field frame of the booster is supported either from the bedplate or from the frame of the converter. The combined booster and converter is, therefore, for all practical purposes, one machine. As the booster armature is mounted between the armature and the collector of the converter, no additional bearings, commutators, collectors or brush rigging are required. Moreover, no additional exterior wiring is required on account of the booster, except for its field circuit. From the operator's stand-

point, the booster-converter is one machine, and thus the objection in this respect to the induction regulator is elimianted. The booster could be made with its armature stationary and field rotating, but this arrangement would require additional collector rings and brush rigging for the booster field, for which no compensating advantage would be obtained; also with this arrangement, it would be impracticable to use series field windings on the booster for regulating purposes. The revolving armature form of booster-converter is shown in Figs. 1, 2 and 3. Fig. 1 shows a 500 kw, 250 volt, 25 cycle

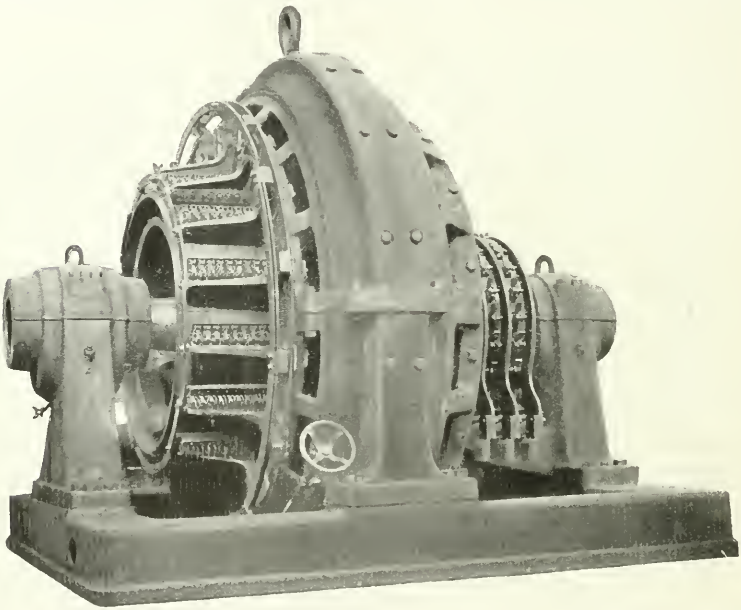


FIG. 3—1 000 KW, 25 CYCLE, 270 VOLT SYNCHRONOUS BOOSTER-CONVERTER SET
Range 230 to 310 volts. Commutator end.

booster-converter with a range of voltage variation from 225 to 275 volts. It is interesting to note that standard converter and generator frames were used for this unit, the bedplate and shaft being the only special parts required. Figs. 2 and 3 show a unit of more compact and uniform design, requiring a special booster frame in combination with the supporting bracket. This machine is a 1 000 kw, 270 volt, 25 cycle unit with a voltage variation from 230 to 310 volts. Eleven of these 1 000 kw booster-converters have been built for the New York Edison and the Brooklyn Edison Companies, and are in successful operation. In these installations the variable volt-

age is desired in order to operate the converters in parallel with storage batteries. The direct-current voltage at the converters is varied by hand to maintain their load constant, the storage battery taking the fluctuations of load. The booster-converters are also used without the storage battery, in which case the booster is used to maintain constant voltage at the center of distribution.

The voltage is varied by means of a special form of motor-operated field rheostat. The field resistance is connected across the exciter bus-bars; leads are carried from each resistance terminal to two duplicate face plates arranged back to back, as shown in Fig. 4, and the booster field is connected between the moveable arms of the rheostats. These connections are shown in Fig. 5; the *front view* connections for both face plates are indicated. The two contact arms are mechanically connected to the same shaft; they therefore revolve in opposite directions when viewed as shown in Fig. 5, one being on the first contact, when the other is on the last contact. By this arrangement the booster voltage can be varied from a maximum in one direction, through zero, to the maximum in the other direction by a continuous unidirectional movement of the rheostat arms and without breaking the field circuit. Although in the particular installations mentioned, the voltage variation is non-automatic, since the gradual nature of the load fluctuations make automatic regulation unnecessary, it can very easily be made automatic by the use of suitable relays to control the motor-driven field rheostat. In special cases where an automatic increase in voltage is desired proportional to the load, the booster may be made with series or with compound-wound fields instead of shunt fields.

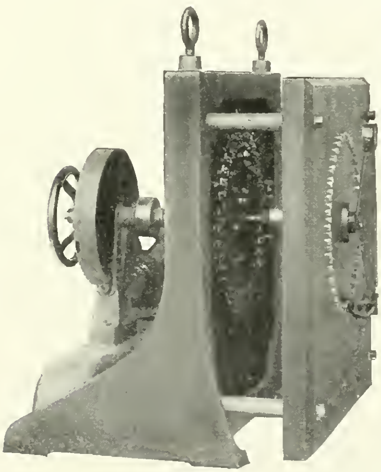


FIG. 4—FACE PLATES OF MOTOR-OPERATED FIELD RHEOSTAT

The booster converter possesses an operating advantage over the induction regulator in that its voltage range can very easily be increased. In the induction regulator the maximum voltage range is fixed by the ratio of primary and secondary turns, as in any

transformer, and by the line voltage. In practical operation it is not feasible to change either of these. With the booster-converter, on the other hand, the maximum range is determined by the maximum booster field current obtainable except as this is limited by the magnetic saturation of the booster. In the New York and Brooklyn installations, this flexibility is taken advantage of by normally operating the booster field in series with a permanent resistance, *A—B*, Fig. 5, which is part of the rheostat. With this resistance in circuit, the voltage of the exciter circuit being normal, the booster field circuit is sufficient to give the 80 volt variation for which the booster is designed. In an emergency the permanent resistance *A—B* can

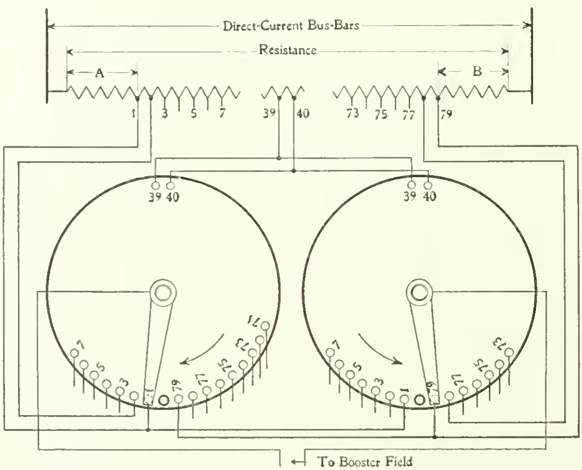


FIG. 5—DIAGRAM OF CONNECTIONS OF MOTOR-OPERATED FIELD RHEOSTAT

be short-circuited, thus putting a higher exciting voltage across the booster field, and the voltage range can be increased 75 percent. This margin in booster voltage requires an unsaturated magnetic circuit in the booster, but since the inherent regulation of the booster is not a factor that need be considered, the booster can readily be so designed.

The booster-converter is somewhat more economical to operate than the induction regulator and the standard converter. The losses in the induction regulator are constant regardless of the amount of variation in the direct-current voltage, since the voltage generated in the regulator is constant. Except for the armature copper loss, variations in the losses in the booster are proportional to the changes in the line voltage, all losses except the armature copper loss being

absent when the rotary converter is operated at the normal voltage of the line.

The advantages of the booster-converter over the induction regulator and standard converter may be summarized as follows:—

1—One piece of apparatus is used instead of two, requiring less maintenance, less floor space and less complicated wiring.

2—Greater flexibility in the range of voltage variation.

3—Better operating efficiency.

THE SPLIT-POLE ROTARY CONVERTER

The method of voltage control by split-pole rotary converters utilizes a different principle from those already described. Variations of the direct-current voltage are secured, not by variation of the impressed alternating-current voltage, but by varying the distribution of the flux under each pole—or as it is usually termed, by varying the field form of the rotary converter. In actual construction, the split-pole converter differs from the standard form only in the field structure. Each pole, instead of being in one piece with one field coil, is made in three sections with three separate exciting coils. This is the form in which the split-pole converter was first conceived. In a later form each pole is divided into two sections.

Upon consideration, it will be evident that the voltage generated in any direct-current machine is proportional to the average value of the flux, or the average ordinate of the field form, between adjacent brushes. A variation of the field form which increases and diminishes the average ordinate will increase and diminish the generated voltage. This is the function of the split-pole with its separate exciting coils. In a direct-current generator, variations of voltage could be secured by simply varying the field form as just described without the necessity of considering any other factor. In a rotary converter, however, the connection to the alternating-current circuit introduces another element. On account of the presence of the alternating-current line voltage, the variation in field form must be accomplished without varying, to a corresponding degree, the wave form or effective value of the alternating-current voltage generated in the converter armature. If this counter-e.m.f. be varied, the difference, either in wave form or effective value, between the line e.m.f., and the counter-e.m.f. will cause a corrective alternating current to flow which will react on the counter-e.m.f. and field form and tend to bring them back to their original values, thus bringing

the direct-current voltage back to its original value. Hence in order to obtain variation of direct-current voltage in a rotary converter by change in field form the field form must be changed without producing a corresponding change in the alternating-current counter-e.m.f. A more familiar example of this same action is furnished by the standard form of rotary converter when the field current is increased in an attempt to raise the direct-current voltage; the only effect is to increase the alternating current. This increase in alternating current is the corrective current required to equalize the counter-e.m.f. and the line e.m.f. and which neutralizes the attempted change in magnetization. The statement that the corrective current brings the alternating counter-e.m.f. back to its original value, either in wave form in the split-pole converter or in effective value in the standard converter is only strictly true when the generating system is infinite in capacity, but in practically all commercial cases, the generating system is so large in comparison with the single converter that the possible modification in wave form, in the one case, or effective value, in the other, is of no practical value in changing the direct-current voltage.

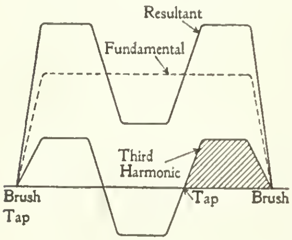


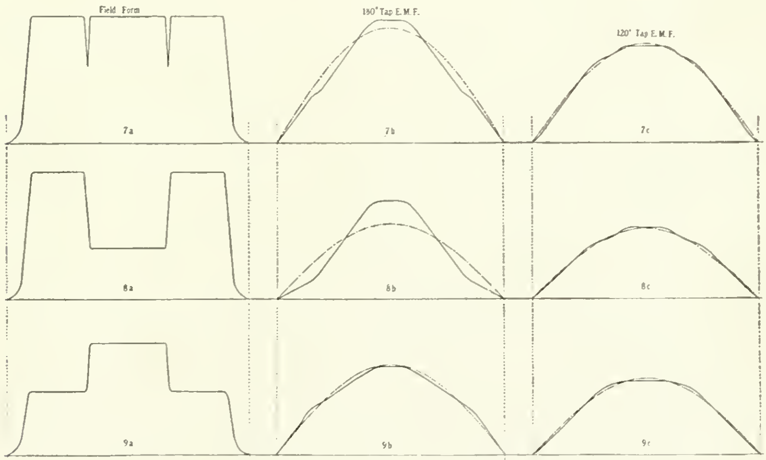
FIG. 6

The split-pole converter, therefore, consists of two essential elements; first, a means of varying the field form, and second, a means of eliminating the variation in alternating-current wave form ordinarily resulting from the variation in field form. It should be kept in mind particularly that only that part of the change in field form which does not produce a change in the alternating-current wave form is effective in changing the direct-current voltage, and that any change in field form which does change the wave form is neutralized by the consequent change in the alternating current.

In describing in detail the action of the split-pole rotary converter, it will be convenient to consider the three-part pole, and the two-part pole types separately.

Three-part Pole Type—The pole structure consists of three approximately equal sections which are equally excited for normal direct-current voltage. A field form for normal voltage is shown in Fig. 7 (a). For higher direct-current voltages the excitation of the outer section is increased and that of the middle section equally diminished, as shown in the field form, Fig. 8 (a). For lower

direct-current voltages the excitation of the outer sections is diminished, and that of the middle section equally increased as shown in Fig. 9 (a). This variation in field form occurs without a corresponding change in the wave form of the voltage between the taps, first, because the field form is varied by superimposing on the original uniform field a third harmonic field, and second, because the alternating-current voltage taps are placed 120 electrical degrees apart as in the delta three-phase winding, or the double-delta, six-phase winding. The reason for these relations will be understood by reference to Fig. 6. It is evident that the armature coils between the 120-degree taps on the alternating-current side will always include two equal and opposite areas of the third harmonic variation of flux,



FIGS. 7, 8 AND 9

which neutralize each other and so produce no change in the alternating-current wave form, while the armature coils between the brushes on the direct-current side (which are 180 degrees apart) will always include three areas of the third harmonic variation in flux, only two of which neutralize each other, thus leaving one to change the average ordinate of the field form and the direct-current voltage.

In the curves shown in Figs. 7, 8 and 9, no attempt has been made to show quantitative values; they are intended to show the nature of the variation in field form; the resulting variation in counter-e.m.f., considering conductors between 180-degree taps, and

finally, how these variations are eliminated in the counter-e.m.f. when conductors between 120-degree taps are considered. The actual wave is shown in full lines and the fundamental sine wave is shown in broken lines. In Fig. 7, *b* and *c* are the respective 180-degree and 120-degree tap e.m.f. wave forms corresponding to the field form for normal direct-current voltage. In Figs. 8 and 9 similar curves for maximum and minimum direct-current voltage are given.

In practice it is necessary to limit the three-pole sections to less than 80 percent of the total pole pitch in order to provide a zero field at the brushes for commutation. This interferes somewhat with the required third harmonic variation, and in actual machines there is some distortion of the 120-degree tap alternating-current wave form which must be corrected by the extra current from the alternating-current line.

On the other hand, various refinements in design, other than the use of 120-degree taps may be employed to reduce the variation in the alternating e.m.f. It is altogether practicable as shown by the curves in Figs. 7, 8 and 9 to reduce the variation in wave form to negligible values.

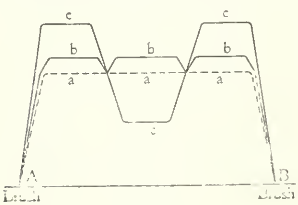


FIG. 10

Size and Weight for a Given Capacity—The three-part pole type of split-pole converter is larger than a standard converter of the same capacity because of the space required for the pole structure and because of the higher maximum flux density required to obtain a given range of direct-current voltage. Both of these features necessitate larger armature diameter and the size of the converter will be determined by that feature which requires the greater increase. The reason for the increase in armature diameter required by the triple-pole structure is self-evident and requires no explanation. The reason a higher flux is required by the split-pole converter is shown by Fig. 10. In the field form corresponding with maximum direct-current voltage, shown in Fig. 8, the same average direct-current voltage could be obtained by one-third the increase in excitation providing the excitation of all three sections was changed in the same direction. This is illustrated by Fig. 10 in which *AaaaB* represents the original field form; *AbbbB* represents the original field form with the excitation of all three sections increased in the same direction, as would be the case if the variation of the direct-current voltage were obtained by variation of impressed alternating-

current voltage; *AcccB* represents the field form with the excitation of the outside sections increased and the excitation of the middle section diminished. While the average ordinate of *AbbbB* is the same as the average ordinate of *AcccB,* the variation in the excitation of the former is only one-third of the variation of the latter. This increase in the maximum flux density required by the split-pole converter necessitates a larger section in the armature teeth which can be secured only by an increase in the size of the converter.

Commutation—It may be seen from the field forms that the variation in excitation does not affect the field at the commutation points. The commutation of the three-part pole type of split-pole converter should be the same as that of a standard converter assuming all other features of design affecting commutation equally good.

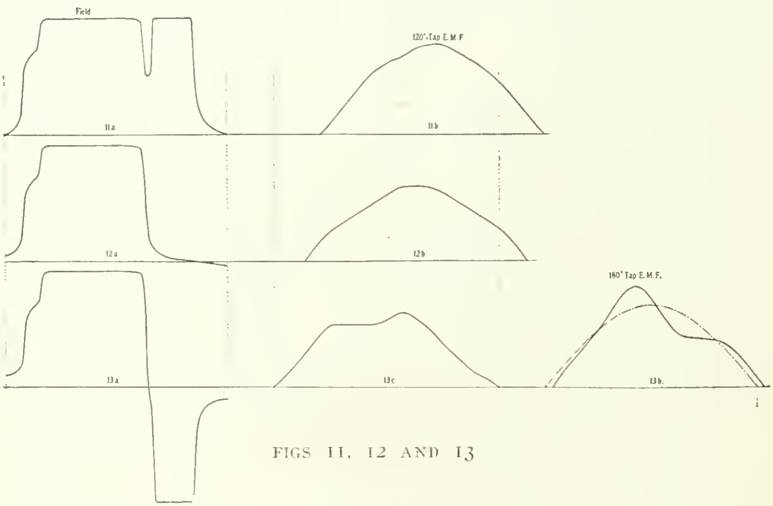
Efficiency—The efficiency of the split-pole converter, on the basis of equal magnetic densities, will be somewhat lower than that of the combination standard converter and booster because of the greater amount of magnetic material and field copper subject to loss. At higher and lower direct-current voltages, the efficiency of the split-pole converter will be lower on account of the higher densities and greater loss in the armature teeth. It should be noted that at lower direct-current voltages the maximum flux density is lower than at normal voltage in the standard converter, but is higher than at normal voltage (and equal to the maximum flux density at maximum direct-current voltage) in the split-pole converter. This makes the efficiency still more in favor of the booster-converter at voltages lower than normal direct-curent voltage.

Power-Factor—There is practically no difference between the three-part pole converter and the booster-converter in ability to maintain unity power-factor. Theoretically there is a slight advantage in favor of the latter.

The Two-Part Pole Type of Split-Pole Converter—The pole structure consists of only two sections, one of which constitutes the main pole and the other, considerably smaller, constitutes the so-called regulating pole. For normal direct-current voltage the main pole only is excited, for higher direct-current voltages the regulating pole is excited in the same direction as the main pole, and for lower direct-current voltages the regulating pole is excited in the opposite direction. The principles involved in the two-part pole type are the same as those in the three-part pole type. The variation in field

form that is *effective in varying the direct-current voltage* is a third harmonic variation, and the three-phase delta, or six-phase double delta connection is employed on the alternating-current side.

These principles are illustrated, for the two-part pole type, by the curves shown in Figs. 11, 12 and 13. In Fig. 11, *a* is the field form for maximum direct-current voltage and *b* is the corresponding 120-degree tap electro-motive force. In Fig. 12, *a* and *b* are the field form and 120-degree tap e.m.f. respectively, for normal direct-current voltage. In Fig. 13, *a, b* and *c* are the field form, 120-degree tap and 180-degree tap e.m.f. respectively, for minimum direct-current voltage. In comparing these curves with the similar curves for



FIGS 11, 12 AND 13

the three-part pole type, it will be noted that the variation in 120-degree tap voltage is much greater in the former curves, and that a relatively wide variation in field form occurs at the commutation points.

If the excitation of the regulating pole is varied without changing the excitation of the main pole, the effective value of the counter voltage of the converter tends to vary, thereby causing currents to flow from the alternating-current side of the converter which prevent this variation. In order to eliminate these corrective currents and maintain the power-factor nearer unity, it is necessary to vary the excitation of the main pole as well as that of the regulating pole. This may be done by varying the shunt field current of

the main winding or it may be accomplished automatically by providing the main pole with an additional winding connected in series with the winding of the regulating poles.

Size and Weight—The space required for the two-part pole is obviously less than that required for the three-part pole. The variation in the maximum flux for a given direct-current voltage range is also less. For these reasons the two-part pole converter is commercially a better design than the three-part pole type. The two-part pole converter, however, is by no means as small as the standard converter, for the same rating and performance. The extra space required for the special pole structure is considerable and such that the design of split-pole converters is limited, even in the two-part pole form, to those for twenty-five cycle systems.

Commutation—With the two-part pole arrangement there is a decided change in the strength of the commutating field as the excitation of the regulating pole is reversed. This is shown by the field forms, Figs. 11 (*a*), 12 (*a*) and 13 (*a*). This is probably the worst feature of the two-part pole arrangement. The variation in commutating field requires at least a readjustment of the brushes whenever the direct-current voltage is changed.

With the unfavorable conditions for commutation peculiar to the two-part pole converter, good commutation can be secured only by making all other features affecting commutation as favorable as possible. Even with the larger converter required by the split-pole design, it is at least uncertain whether the commutation can be made as satisfactory as in the smaller equivalent standard converter.

Efficiency—The efficiency of the two-part pole converter is inherently better than that of the three-part pole type, both on account of the smaller amount of active material subject to loss and to the smaller range in magnetic flux required. It is not so simple to compare the efficiencies of the two-part pole converter and the combined standard converter and booster. Assuming equal material in the two types, the comparison is probably in favor of the split-pole converter at maximum voltage, and in favor of the booster-converter at minimum voltage.

Power-Factor—In the two-part pole converter it follows that as it is not possible to approximate the required third harmonic variation in flux as closely as in the three-part pole type, larger corrective currents will flow and the power-factor will be further from 100 percent. This variation from 100 percent power-factor is

caused by the difference in wave shape rather than by a difference in effective value between the impressed alternating-current voltages and the counter-e.m.f.'s A variation in power-factor, due to a difference in effective value also results whenever the regulating field is changed, if the main field is not properly adjusted.

Station Layout—From the standpoint of the station layout, the split-pole and booster types of machines are identical. Both may be wired direct to the lowering transformers and both require the extra wiring for the regulating field circuit and rheostat. Both require approximately the same floor space. In maintenance, both machines are also the same, assuming that they are of equally good performance.

Comparison of Types of Machines—In considering any new type of machine, the main question is not whether its operation is based on a reasonable theory, but whether it accomplishes its purpose more cheaply or more effectively than other existing apparatus designed for the same purpose. If the split-pole converter is to supplant other types of converter, it must not only do as much as they, but it must do it for less cost or do it more effectively. From this point of view there does not seem to be a sufficient justification for the introduction of a new type of machine. The split-pole converter does not accomplish any new thing, nor does it do old things more conveniently, more economically, or with less first cost than existing apparatus.

CONSTANTS OF SINGLE-PHASE RAILWAY CIRCUITS

A. W. COPLEY

THE resistance and impedance of a circuit transmitting power from a power house to a sub-station may be found when current of a given frequency is carried by conductors of definite size and material and in definite positions with respect to each other. The electro-motive force and power required for sending current through such a circuit may be determined from these constants, the e.m.f. being determined by the impedance and the power by the resistance. The effective resistance is, of course, independent of the positions of the wires. It may be different for different frequencies and higher for alternating than for direct current. The loss in metallic circuits of ordinary sized copper wire is practically the same for direct current and alternating current of commercial frequencies. The difference between the resistance to alternating and direct current depends upon the size and material of the conductor, a large conductor showing larger difference than a small one on account of the fact that induced currents are set up in the conducting material, resulting in unequal current density in the conductor, the density being greatest near the surface. This phenomenon is known as "skin effect." A magnetic conductor shows more difference in effective resistance between alternating and direct current than a non-magnetic one. This is because the skin effect is more pronounced owing to the stronger magnetic field inside the conductor, which causes larger induced currents.

In a graphical representation, the impedance is the vector sum of the resistance and the reactance; the two quantities being at right angles. The reactance is caused by the counter e.m.f. set up through the action of the magnetic field surrounding and within the conductors. Its magnitude depends upon the size and position of the conductors, large conductors having less reactance than small ones and conductors spaced far apart having more reactance than conductors near each other. In a direct-current circuit the loss of power and the loss or drop in voltage between the generator terminals and the load, are readily found when the current and resistance of the circuit are known. The percent loss in power in the circuit is equal to the percent drop in voltage. With direct-current

the reactance is zero, and the impedance and resistance are equal and identical. To determine these constants for any alternating-current circuit, it is necessary to know the size, material and relative positions of the conductors. In a railway circuit consisting of a copper trolley wire suspended from steel messenger cables and steel rails in contact with the earth for return conductors, the position, size and material of the trolley wire and rails are fixed, but the path of the current through the earth is indefinite and indeterminate. As the return current divides between the earth and the rails, the calculation of the constants of such a circuit is difficult. The division of current between rails and earth is different for direct and alternating current, and also the distribution of current in the rails and earth. The rails, being of iron, have considerably higher effective resistance to alternating than to direct-current on account of skin effect, as mentioned above. The effective resistance is assumed as the value found by dividing the power loss in watts by the square of the current in amperes, and is given in ohms. In other words it is the number of ohms which, with an equal direct current, would give the same actual loss. The percent loss in voltage in an alternating-current circuit depends upon the constants of the transmission circuit and upon the power-factor of the load. It is convenient to determine the constants of a transmission circuit by short-circuiting the load and measuring watts, volts and amperes. The volts divided by the amperes gives the apparent resistance or impedance. The watts divided by the square of the amperes gives the effective resistance and the square root of the difference of the squares of these two values gives the reactance.

In addition to the division of current between the rails and the earth, another factor which is necessary for the determination of the constants of the circuit is the resistance of steel rails with bonds. Tests for the determination of constants for such circuits have been made on the circuits of the New York, New Haven & Hartford Railroad, and also on the circuits of several single-track interurban roads. From the results of these tests it is possible to calculate the constants for single-track, double-track, and four-track roads. The most extensive and important investigations were those made on the New Haven Road.* The railroad is a four-track road and is equipped with the single-phase system from Stamford, Conn., to Woodlawn, N. Y., the power house being located at Cos Cob, seventeen miles

*The tests were conducted by the writer under the general direction of Mr. W. S. Murray, Electrical Engineer, N. Y., N. H. & H. R. R. Company, and Mr. Chas. F. Scott, Consulting Engineer, W. E. & M. Co.

from the Woodlawn end and five miles from the Stamford end of the electrified section. Current is fed from the power house to four 0000 rolley wires each supported by two 9/16 inch steel messenger cables. The return circuit for the current is through the eight 100-lb track rails in parallel which are bonded with 000 copper bonds.

RESISTANCES

Trolley Resistance—Measurement of the resistances to alternating current of the trolley circuit is not as simple a matter as it may appear. The resistance of the trolley wire and messenger cables alone is comparatively easy to measure. The method employed on the New Haven road was that of supplying current to one trolley wire and using another trolley wire as the return conductor; by measuring the current, voltage and power, the resistance was then calculated.

Rail Resistance—In the determination of rail resistance the total loss in watts in the trolley-rail-earth circuit can be measured and the trolley loss subtracted from this; the result thus obtained, however, gives the power lost in the combined rail and earth circuit. In another method which was used, telegraph wires were connected to the rails at two points between which the rail current was known to be fairly uniform and measurement made of the voltage and the power, the wattmeter circuit being so arranged that the current coil of the meter would measure the current flowing in the rail. This method, however, also allows errors to enter. The voltage in the telegraph wire includes, beside the voltage drop in the rail, induced voltages from the trolley, rail and earth currents. The taking of the wattmeter measurements eliminates the induced voltage due to the rail current but only part of that due to the trolley and earth currents, and therefore the induced e.m.f.'s due to them are not in phase with each other. This difficulty was finally eliminated by running the voltage wire along the web of the rails, thereby practically eliminating the induced e.m.f.'s in the voltage circuit due to trolley and earth currents.

Values Obtained—It was found that the resistance to 25-cycle current of the 0000 copper trolley wire with 9/16 inch steel messenger wires is not appreciably different from the resistance of the copper wire alone to direct current. The messenger wires carry only a small proportion of the current because of their high resistance compared with that of the copper trolley wire. The value of the resistance at 25 cycles was found to be about 0.26 ohms per mile.

The same value was found for 17 cycles, thus showing that there is practically no variation with frequency.

Measurement of the resistance of the rails by the use of a voltage wire laid along the web of the rail for a thousand feet, and taking voltmeter, ammeter and wattmeter readings gave an average result of 0.16 ohms per mile for single rail, 25 cycles and 0.065 ohms for direct current, the ratio between the two resistances being about five to two. Using these values, the resistance for single tracks (two rails) is 0.08 ohms per mile for 25 cycles. The measurements were made with various current densities ranging from 40 to 200 amperes per rail and the resistance was found to be constant over this range. Tests made with a telegraph line wire for a voltage wire showed wide variation and were not satisfactory. The average value of resistance at 25 cycles for single track found in this manner was 0.092 ohms per mile which is about 15 percent higher than the value found in the more reliable manner.

REACTANCE

The reactance of the railway circuit is, as already explained, made up of two fundamental components, viz., the internal reactance due to the magnetic field inside the conductors, and the external reactance due to the field between the conductors. The former is large as compared with the latter.

Internal Reactance—The internal reactance of the conductors is a counter e.m.f. which depends in amount upon the size and material of the conductors. The resistance of steel rails is higher than that of comparatively small copper wire. No measurement was made of the internal reactance of the trolley wire, but the calculated value of 0.013 ohms per mile was assumed as correct.

The internal resistance of the rails was measured approximately by making use of the voltage wire run along the web of the rail. The e.m.f. in this wire, which is equivalent to the impedance volts drop in the rail, is made up of two components, one the resistance volts, the other the reactance volts. As in a graphical representation, these are at right angles to each other and the wattmeter and ammeter readings determine the resistance volts, the reactance volts can easily be calculated. The value found in this was 0.04 ohms per mile of single track for 25 cycles.

External Resistance—The reactance due to the field between conductors was found by measurement of the total impedance volts in the circuit made up of trolley wire, with rail and earth return, and subtracting from this the sum of the resistance volts in the cir-

cuit and the reactance volts internal to the conductors. The quantities are all vector quantities, hence the angular relations must be taken into account in making the subtraction.

Values Obtained—The values so found agreed very closely with previously calculated results which were deduced from the values of current in the trolley wire and rail and earth circuits and the distances between these conductors as measured. The earth current was assumed to be so far below the surface that it would have practically no effect on the value of the reactance, due to the interaction between the rail and trolley. In this manner, also, the reactance was figured for double and single track. For the latter the value is about 0.44 ohms per mile at 25 cycles.

IMPEDANCE

The measurement of the impedance of the various parts of the circuit is essential to the determination of the reactances given in the preceding paragraphs. The impedance of the circuit as a whole is obtained from volt-meter and ammeter readings at the end of the circuit where power is fed to the trolley wire. For these tests the trolley wire was grounded to the rail at one end, current being supplied at a low voltage to the other end. At 25 cycles the impedance of single track road with 0000 trolley wire and 100-lb. rails was found to be about 55 volts per mile per 100 amperes. As the power-factor of the load and of the line are not greatly different, this closely represents the difference between the electro-motive force at the power house and at the load.

DIVISION OF CURRENT BETWEEN RAILS AND EARTH

On single-track roads, of the total current returning to the power house from a load at a given point on the circuit, it has been found that about 70 percent flows in the rails toward the power house and this gradually decreases to about 40 percent after the first two or three miles, at which value it remains constant to within a short distance of the power house, and the remaining 30 percent flows in the rails in a direction away from the power house, leaking to the earth over a distance of about three miles.

The action on a four-track road is similar except that instead of 30 percent flowing from the power house, only 12 or 13 percent flows in this direction, and the remaining 87 percent drops to 75 percent in the first two miles and stays at that value to within a short distance of the power house. A measurement of phase differ-

ence between the trolley and rail currents was made on the New Haven road, which showed an average of about six degrees lag for the rail currents.

The following tables were compiled from the results of the tests.* The values of impedence and resistance given are in volts per 100

TABLE I—FOUR TRACK ROAD—FOUR 4/0 TROLLEY WIRES, EIGHT 100 POUND RAILS

ELECTRO-MOTIVE FORCE—VOLTS			DIVISION OF CURRENT—AMPERES		
Resistance	25 cycle	15 cycle		25 cycle	15 cycle
Trolley	6.8	6.7	Each outside trolley wire	26.6	26.3
Rail	1.8	1.5	Each inside trolley wire	23.4	23.7
Total	8.6	8.2	Rails	75	
			Earth	25	
Reactance					
Trolley Wires—Internal	0.35	0.2			
Rails—Internal	0.85	0.5			
Between Trolley wires and return circuit	15.6	9.4			
Total	16.8	10.1			
Impedance—Total	18.9	13			

TABLE II—DOUBLE TRACK ROAD—TWO 4/0 TROLLEY WIRES, EIGHT 100 POUND RAILS

ELECTRO-MOTIVE FORCE—VOLTS			DIVISION OF CURRENT—AMPERES	
Resistance	25 cycle	15 cycle		25 cycle
Trolley	13	13	Rails	58
Rail	2.5	2	Earth	42
Total	15.5	15		
Reactance				
Trolley Wires—Internal	0.6	0.4		
Rails—Internal	1.2	0.7		
Between trolley wires and return circuit	25.1	15		
Total	26.9	16.1		
Impedance—Total	31	22		

*These tables also appear in the Trans. of the A.I.E.E., where they were presented as part of the discussion on "From Steam to Electricity on a Single-Track Road," by Mr. J. B. Whitehead.

TABLE III—SINGLE TRACK ROAD—ONE 4/0 TROLLEY, FOUR 100 POUND RAILS

ELECTRO-MOTIVE FORCE—VOLTS			DIVISION OF CURRENT—AMPERES	
Resistance	25 cycle	15 cycle		25 cycle
Trolley	26	26	Rails	40
Rail	3	2		
Total	29	28	Earth	60
Reactance				
Trolley Wires—Internal	1.3	0.8		
Rails—Internal	1.5	0.9		
Between trolley wires and return circuit	44.2	26.5		
Total	47	28.2		
Impedance—Total	55.3	39.6		

amperes per mile of trolley wire. The impedances are practically equal to the difference between the e.m.f. at the power house and that at the load. For the practical calculation of commercial circuits, the tables give the power loss and the total voltage drop per mile per 100 amperes. The trolley wires are taken as 0000 copper and the rails as 100 lb. steel. With 000 trolley wire instead of 0000, for single track, the total impedance in volts per 100 amperes per mile is 50. The earth losses are left out of the table. Such losses are usually small and are not easily measured. Moreover, they undoubtedly vary greatly with different kinds of soil and ballast of road-bed, the largest part of the loss occurring in the region where the current is leaving the rails and going into the earth.

TABLE IV—POWER LOSS, RESISTANCE VOLTS, AND VOLTAGE DROP, DIFFERENCE BETWEEN E.M.F. AT POWER HOUSE AND LOAD, PER 100 AMPERES PER MILE

LOSS—WATTS	25 cycle	15 cycle	DROP—VOLTS	25 cycle	15 cycle
Single Track	29	28	Single Track	55	40
Double Track	15.5	15	Double Track	31	22
Four Track	8.6	8.2	Four Track	19	13

A NEW SYSTEM OF SUB-STATION RELAYS FOR INCOMING TRANSMISSION LINES

PAUL MacGAHAN

In order to insure against interruption of service on a transmission system, a minimum of two transmission lines operating in parallel has been found to be essential. There are advantages in using a greater number of lines in parallel, but these advantages are not in proportion to the increased cost, except upon very large systems. Assuming the most general case of a sub-station fed from a generating station, by means of two parallel transmission lines, the question of automatically cutting out a line which develops a ground or short-circuit, without interrupting service over the other lines, has been one of the problems of long distance transmission of power. It is desirable to have a means for automatically cutting out the defective lines quickly and effectually so as to prevent the loss of any synchronous load that may be in operation on the system. Until recently, this has seemed to be an impossible accomplishment, but tests made upon one of the transmission systems distributing power from Niagara Falls prove that a device has been developed which will do the work in a satisfactory manner.

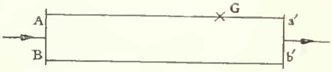


FIG. 1

To disconnect the defective line at the transmitting end is a simple matter, and is accomplished by means of ordinary overload relays, preferably equipped with an inverse time element, or any similar device arranged to trip the circuit breakers when an overload occurs. The ground or short-circuit will continue to be fed back from the sub-station bus-bars, as shown in Fig. 1, in wheih *Aa'* is the defective polyphase line, short-circuited or grounded at *G*, and *Bb'* the clear line. It is evident that the direction of flow of power in one or more of the phases is in the reverse direction at the point *a'*. The main problem, therefore, is one of designing satisfactory reverse current relays to be installed at points *a'* and *b'*. As a short-circuit may cause the voltage to drop to an exceedingly low value, relays for this purpose must be operative at these low voltages, as well as at the low power-factors which may also be caused by the break-down. Moreover, the action under such condition should be practically instantaneous, so that the synchronous load will be maintained.

A brief review and description of the various devices previously used for this purpose in the past, and the reasons for their failure to give sufficiently complete protection under all conditions, will assist in understanding the latest device developed for this purpose.

The first devices used consisted of wattmeters equipped with contacts which would be closed by the action of the wattmeter coils when the direction of power was reversed, thus tripping the circuit breakers. The wattmeter type relays were found inadequate, for the reason that at low voltage and low power-factor, their torque was insufficient to operate the contacts. An attempt was made to interpose a special transformer designed to hold up the voltage, between the wattmeter shunt coil and the circuit, this transformer being provided with a secondary coil wound over an iron core whose cross-section was very small where it passed through the secondary coil, and which was designed to have a large magnetic leakage. The maximum voltage-sustaining effect that could be obtained by this means was a decrease of secondary voltage proportional to half the rate of the primary decrease in voltage, until one-third of normal voltage was reached, below which the secondary voltage decreased approximately at the same rate as the primary. Thus, this transformer had little or no effect in improving the operation at very low voltages.

Mr. H. G. Stott, in his paper before the American Institute of Electrical Engineers on July 1, 1903, stated that, "Reverse-current relays at the receiving end of the feeders operate satisfactorily, provided the fault is not severe enough to drop the potential. If, however, the fault amounts to a short-circuit, the potential at the receiving end will fall so low that the potential coil of the differentially-wound (reverse-current) relay will not receive enough current to enable the relay to operate. Reverse-current relays at the receiving end of feeders are not as yet to be depended on, but recent improvements give promise that we may soon expect to find a satisfactory solution of this important problem."

At the time Mr. Stott wrote the above, the devices available for this purpose were, in general, of the following classes: 1—Contact-making wattmeter type; 2—Choke coil devices; 3—Differential relays.

A system devised by Mr. L. Andrews, in England, consists of a method connecting the incoming feeders through choke coils having a middle tap from which the combined currents are taken. Under normal conditions the windings of the choke coil are in op-

posite directions, thus producing no magnetization and consequently no choking effect. When current in one side reverses, the choking effect prevents a rush of current to the defective line. The capacity of the choke coil is sufficient to prevent a surge of current great enough to disturb the system or to reduce the voltage to below one-half of normal.

The design features of the differential relay have been fully discussed by Mr. Geo. F. Chellis in his paper before the A. I. E. E. on May 16th, 1905. In referring to the relays on the receiving end of parallel transmission lines, Mr. Chellis states that he "does not know of an alternating-current reverse-current relay the operation of which does not depend upon the pressure of the system, nor of a relay that depends upon the pressure operating on a reversal only, that would not become completely inoperative at zero pressure or comparatively low pressures." This was true at the time Mr. Chellis wrote his paper, but as foreseen by Mr. Stott such a relay is now available.

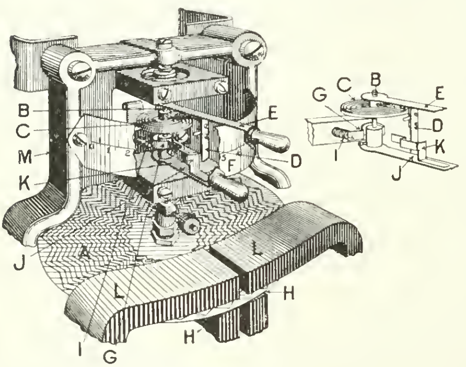


FIG. 2—CONSTRUCTION DETAILS OF SINGLE-PHASE ALTERNATING-CURRENT OVERLOAD AND REVERSE CURRENT RELAY — INVERSE TIME ELEMENT ACTION

The next step forward in the development of a reverse-current alternating-current relay was an improvement in the windings of the wattmeter type relay, by means of which the relay became operative on zero voltage or on zero power-factor. This design, which was due to Mr. Frank Conrad and, as originally brought out, consisted of a polyphase wattmeter movement with coils arranged so as to produce torques proportional to the current and the voltage, these torques being opposed by a torque proportional to the watts, and thus differing considerably from the principle used in the differential relay. The mechanical construction of the integrating induction wattmeter was used, but instead of driving the usual registering dial, the shaft was controlled by a spring, and a moving arm was arranged to close the contact. The motion of the disc was damped by means of permanent magnets. In its present form, this relay is

made in single-phase units instead of polyphase, as it has been found that three single-phase units on each three-phase line give the most complete protection. Trouble confined to one phase only will thus cause a relay to operate whereas, if a polyphase relay is used, the effect of a reversal in one phase only upon the total torque of the relay may not be sufficient to counteract the torque of the electromagnet connected across the other phase, and tripping would not be accomplished. A convenient form of adjustment is provided, to allow of control of the time element without varying the load setting.

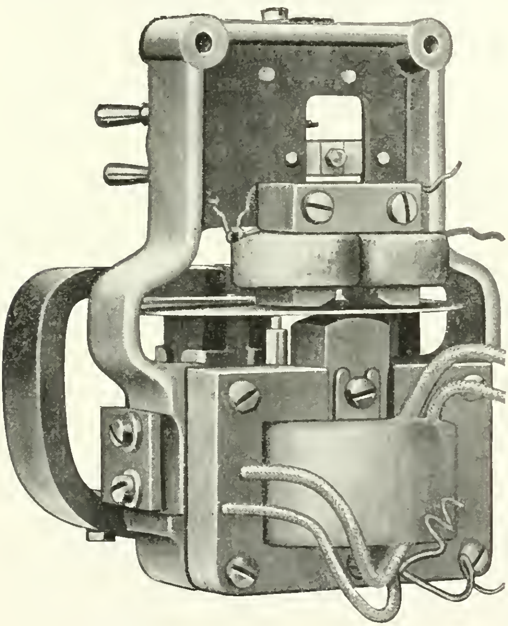


FIG. 3

Referring to Fig. 2, *A* represents the aluminum disk of the relay attached to shaft *B*. The latter is mounted in bearings in a manner similar to that of an induction wattmeter, that is with a ball bearing below and a pin bearing above. *C* is a spiral control spring attached at its inner end to the shaft *B* and at the outer end to an arm *D*, which terminates in an adjustable index arm *E*, movable over a graduated scale *F*. *G* is a contact arm attached to the shaft *B*. The arm *G* terminates in a contact which in its travel engages the stationary insulated contact *I*, thereby completing the trip circuit. The spring, in addition to controlling the movement of the relay, serves to carry the tripping current into the movable contact.*

Fig. 3 shows a single-phase relay unit with cover and base removed. With both voltage and current applied to the relay, its action is selective, the operation on reversal of the power occurring

*For a complete description of the design and operation of this relay refer to article on "Single-Phase Alternating-Current Overload and Reverse-Current Relays" in the series on "Protective Relays" by Mr. M. C. Rypinski, in the JOURNAL for May, 1908, p. 286.

at lower values than under the normal power condition. With voltage alone applied to the relay, it is still operative, but to a lesser degree due to the interaction of C and E, Figs. 4 and 5. With only current applied, the coil C acts as a secondary to D, energizing E and thereby creating an operating torque condition. An external series resistance is interposed between the voltage binding posts and the voltage transformer. The current path, due to current alone, is shown in Fig. 4, the connections being the same as is used in induction ammeters. The curent path due to voltage alone is shown on Fig. 5. There is sufficient torque developed in this circuit to give a deflection at full voltage of one-fourth that due to full current alone. The current paths which develop torque proportional to the true watts will be apparent if the coil C is considered as open-circuited, the remaining connections being theoretically the same as in wattmeters.

The current coil D is arranged in three sections with taps brought out to the terminal block on the relay base. This block supports four teminal posts, three of which are grouped around the fourth and provided with a link which can be used to connect the central terminal with any one of the three outside terminals, numbered respectively *1*, *2* and *3*. With the link connected to *1*, all the turns of D are in circuit and the relay is in the condition of maximum sensibility; i. e., it may be set for its minimum tripping values. With the link connected to *3*, only about 50 percent of the turns are in circuit and the relay is in the condition of minimum sensibility and may be set for maximum tripping values. The connection to *2* gives tripping values intermediate between *1* and *3*.

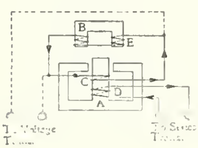


FIG. 4

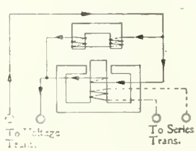


FIG. 5

With both current and voltage applied, the operation of the relay for various settings and internal connections is as indicated in Table I, the tripping values being given in terms of the current flowing in the relay and the voltage being normal and in phase with the current (100 percent power-factor). Tripping values are given for both directions of power or current delivery, i. e., in the normal or load direction and in the reverse direction. It will be noted that the reverse values are less than the load values, varying from one-third to one-eighth of the latter depending on the setting of the relay. A set of these values corresponding to internal

connections No. 1 and plotted to rectangular co-ordinates is shown in the performance curve, Fig. 6. The use of this type of relay on generator circuits presents many advantages.

Ordinarily generator protection against overloads due to service requirements is undesirable, but in the case of a short-circuit on the bus-bars, the generators should be cut out automatically. The characteristics of the form of reverse-current relay described are such as

TABLE I—VALUES OF CURRENT CAUSING OPERATION OF RELAY WITH VARIOUS SETTINGS AND INTERNAL CONNECTIONS

Setting of Upper Index on Relay Scale	AMPERES IN RELAY TO CLOSE CONTACTS					
	Load Direction—Internal Connections			Reverse Direction—Internal Connections		
	No. 1	No. 2	No. 3	No. 1	No. 2	No. 3
0	6.1	7.8	10.8	0	0	0
2	7.0	9.0	12.4	.0	1.2	1.6
4	7.7	9.8	13.7	1.5	1.9	2.7
6	8.2	10.5	14.6	2.1	2.7	3.7
8	8.7	11.1	15.5	2.6	3.3	4.6
10	9.2	11.8	16.4	3.1	4.0	5.5

to make this possible. It can be set so that, at approximately normal voltage, such as is incident to service overloads, the relays cannot trip out, but should an actual short-circuit on the bus-bars occur, the voltage will drop and allow the relay to trip out at much lower values. Thus, if the relay is set to trip at 7.7 amperes in the secondary of the series transformer at normal voltage, which is in excess of what the generators could possibly deliver, it will be seen by referring to Fig. 7 that the relay will trip at four amperes at zero voltage, this being below the "short-circuit value" of the current delivered by the generator. In the case of a fault in one of the generators causing current to flow in the reverse direction, the relay will act as an ordinary reverse relay, tripping the circuit breaker instantly.

Mr. Chellis, in his paper before the A. I. E. E., May 16, 1905, discusses the necessary characteristics of a relay when installed on a generator circuit. He says, "Assuming that a relay is to operate on short-circuits and reversal, but not on overload at normal pressure, the ideal relay should have the following characteristics:

1—It should permit the alternator to be loaded to its maximum current capacity at normal pressure.

2—It should limit the current on short-circuit to not more than 75 percent of the short-circuit current of the alternator.

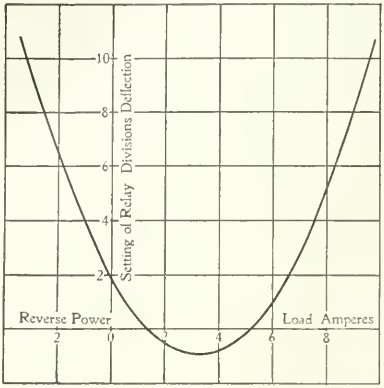


FIG. 6—CURVE SHOWING OPERATION OF RELAY WITH CURRENT AND VOLTAGE APPLIED

Plotted from values in Table I corresponding to internal connections No. 1.

3—It should limit the current on reversal to the lowest value at which no difficulty is experienced when synchronizing (i. e., it should permit the flow of the ordinary cross-currents without operating).

4—It should be provided with a positive time limiting device, the adjustment of which is independent of the curent value at which the relay is operated."

Taking up again the case of the two parallel transmission lines, it is evident that the form of relay above described, if installed at the receiving end, will afford protection under all conditions of low voltage or low power-factor. If, however, the fault is such as to reduce the voltage to approximately zero, i. e., as represented by the curve, Fig. 7, it will be noted that the time elements of the relays on both the incoming lines will be approximately the same, and therefore both breakers will trip, interrupting the continuity of service. The limiting value of the voltage required is about 50 percent of normal; below this, the difference between the time elements is less than the time required for the electrically-operated switches to act, so that selective action would not take place.

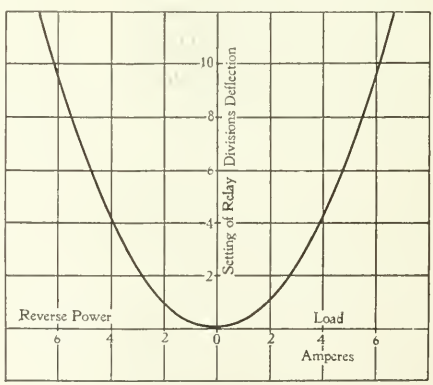


FIG. 7—CURVE SHOWING OPERATION OF RELAY WITH CURRENT ONLY APPLIED

On systems subject to accidental conditions which would pro-

duce a reversal of power at very low voltage, and when continuity of service must be maintained, recourse may be had to an additional selective device, the function of which would be to instantaneously open the trip circuit of each relay when the power is in the positive direction, thus preventing the main relay from completing the trip circuit when it makes contact. This selective device is an ordinary contact-making wattmeter type relay with the contacts adjusted so that at zero power, its contacts are closed; but the control force is so slight that the contacts will be opened when the watts are five or more in the positive direction, the full load rating of the coils being five amperes, 100 volts, or 500 watts. Thus when a short-circuit

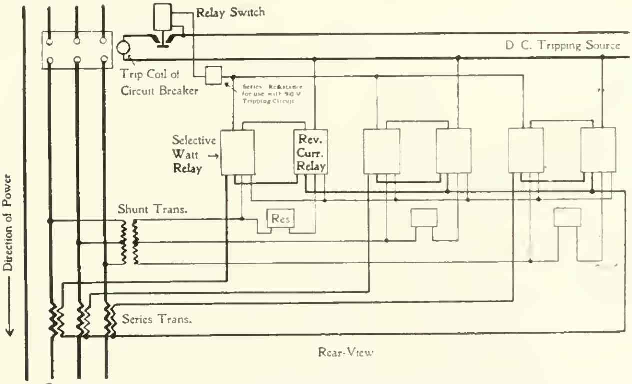


FIG. 8—CONNECTION DIAGRAM FOR COMBINATION OF THREE SINGLE-PHASE REVERSE-CURRENT RELAYS AND THREE SELECTIVE WATT RELAYS ON A THREE-PHASE FOUR-WIRE CIRCUIT

occurs just outside the receiving station, the voltage being barely sufficient to cause a destructive flow of current, a voltage of one percent of normal at full-load current would be sufficient to operate this selective device. A complete diagram of connections for the relay circuits is shown in Fig. 8.

A very elaborate series of tests was made on February 2nd at Syracuse, N. Y., on the above combination of overload and reverse-current relays with selective watt elements, using for this purpose artificial grounds upon one of the long distance transmission lines of the Niagara, Lockport & Ontario Power Company, as indicated in Fig. 9. These grounds varied from 1 000 ohms to a "direct ground." The line voltage was normally 66 000 volts. The reverse-current relays with the selective devices were installed on the incoming lines at Syracuse. The tests were planned and conducted by Mr. S. Piek, Superintendent.

In the above typical cases (and in other special tests as well) the defective line was disconnected in a satisfactory manner, and the synchronous loads at the sub-stations on the "good" trunk line were not affected. Continued experience in actual commercial service in various installations, has been of a highly satisfactory character.

It may be asked, in connection with the relay arrangement described above, whether, inasmuch as the selective watt relay is operative on one percent of normal voltage, it would not be sufficient in itself for obtaining full protection without the use of the overload and reverse-current relay in addition, and consequently whether the development of reverse relays has not been in the nature of a circle, with a logical return to the original principle, improved mechanically only. The folowing consideration will illustrate the advantages gained by the selective watt relay. Assume that the reverse-current wattmeter type relay, as above described, is arranged to have its contacts normally open, and adjusted so as to trip at two percent reversal, with a range from two to ten percent possible adjustment. In this case the relay will have to develop sufficient torque to effectually close the contacts; if it fails in this, it fails utterly, as it will not trip the circuit breaker. Moreover the necessarily delicate adjustment would often result in a tripping of the circuit breakers due to vibration or to slight reverse surges such as occur during synchronizing. In the case of the selective watt relay, however, the spring torque by itself is sufficient to close the contacts, and thus insure the tripping of the circuit breaker. If there is insufficient torque to open the contacts, there is, of course, no selective action and both circuit breakers trip, in other words, the condition corresponds to that existing when only overload and reverse relays of the type above described are used. Thus, in the case of accidental conditions which reduce the voltage to a low value, the additional selective watt relays add to the probability of successful maintenance of service; if they fail to operate, the main relays will nevertheless afford protection by tripping the circuit breakers.

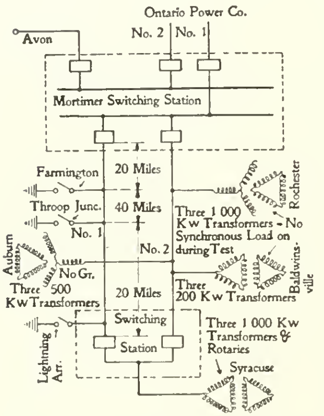


FIG. 9—ARRANGEMENT OF TRANSMISSION SYSTEM ON WHICH SERVICE TEST OF RELAYS WAS MADE

ELECTRIC RAILWAY ENGINEERING—X

SUB-STATIONS, HIGH-TENSION LINES AND POWER HOUSES

F. E. WYNNE

HAVING determined the sub-station locations, the next step is to find the capacity required in each sub-station, and to choose the units in which this capacity shall be installed together with the necessary auxiliary apparatus. In city systems the capacity for each sub-station may be determined on the basis of the average load as estimated from the average current per car and the average number of cars receiving power from that station. For example, a certain sub-station may supply an average load of fifteen cars, each taking an average current of 100 amperes. The average current from the station is then 1 500 amperes. At 600 volts this current shows an average station load of $600 \times 1\,500 \div 1\,000 = 900$ kw. Hence, the rated capacity of the sub-station machinery should be about 900 kw. In using this method, care must be taken to provide sufficient capacity to handle the load during rush hours. With suitable division of the average capacity between two or more units, it will often be found that the rush hour load can be cared for by a single machine of the same size as the units selected for the average load, this machine being a reserve unit except during the rush hours; or, storage batteries of sufficient size to take the extra load may be installed. Throughout city systems with reasonably frequent service, the average load is the principal factor in determining the size of sub-station units, although the maximum average load may fix the total station capacity.

On interurban lines, where the service is more or less infrequent in comparison with city lines, the sub-stations are subject to excessive variations in load and the average load is small as compared with the maximum demand. This fact makes it necessary to select the sub-station capacity with reference to the maximum load rather than the average load. Having determined from the train sheet the probable maximum load which may fall on a sub-station, the capacity to be installed should be not less than two-thirds of this maximum load. This permits the station equipment to carry a maximum overload of fifty percent for short periods. It is advisable to limit the estimated overload to this amount because there always exists the possibility of considerably greater momentary overloads and the station equipment should not be expected to carry overloads in ex-

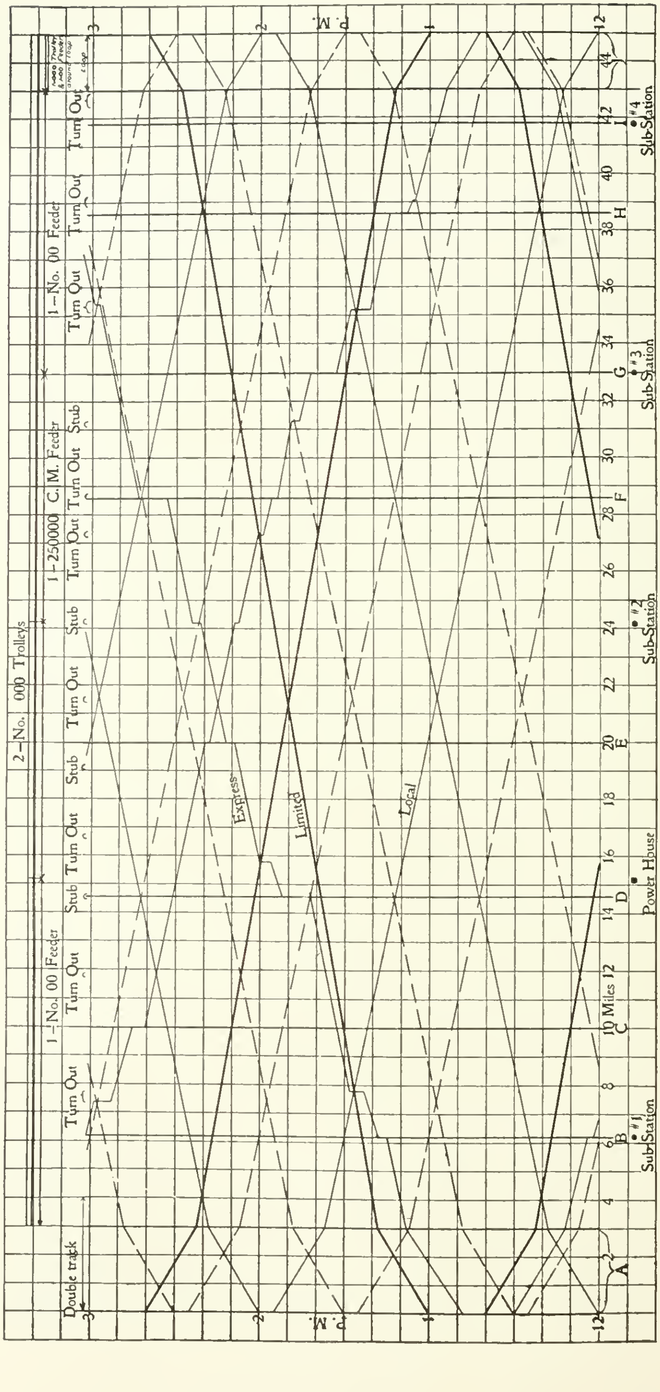

2—No. 000 Trolleys
1—No. 00 Feeder
1—250000 C.M. Feeder
1—No. 00 Feeder
Double track
Turn Out
Stub
Express
Limited
Local
P.M.
A
B
C
D
E
F
G
H
I
10 Miles 12
Sub-Station #1
Power House
Sub-Station #2
Sub-Station #3
Sub-Station #4

FIG. 1

cess of 100 percent even momentarily. An excellent check on this method of choosing sub-station capacity is obtained by the following arbitrary rule. From the train sheet determine the probable maximum load on the sub-station. Install one kilowatt in rated sub-station capacity for every two horsepower in car equipments drawing more than one-half of their total current from that sub-station, and one kilowatt per four horsepower for those cars which are taking less than one-half current. This rule is based upon the conditions existing on operating roads. The selection of sub-station capacities may be illustrated by referring to the train sheet, Fig. 1. The probable maximum load on sub-station No. 1 occurs about noon when two cars are drawing all of their power from this source and one car between it and the power house is taking 72 percent of its power from the sub-station. If now one of the cars adjacent to the sub-station and the car between the sub-station and the power house are assumed to be starting and taking 500 amperes per car and the third to be running at 240 amperes, the maximum load on the sub-station is $600 \div 1\,000\ [500 + (72 \div 100) \times 500 + 240] = 660$ kw. The capacity to be installed should approximate $660 \div 1.50 = 440$ kw. Checking this value by the rule, the necessary capacity* is found to be $3 \times 4 \times 75 \div 2 = 450$ kw.

For sub-station No. 2, the maximum load probably occurs at 2:20 p. m., with two cars adjacent to the sub-station and one leaving *E*. The two adjacent cars draw practically all of their power from sub-station No. 2 and the car at *E* takes about 330 amperes from sub-station No. 2, so the total maximum load on sub-station No. 2 is $600 \div 1\,000\ (500 + 240 + 330) = 642$ kw and the capacity required in sub-station No. 2 is $642 \div 1.50 = 428$ kw. The arbitrary rule again gives 450 kw as the required capacity of the sub-station.

On sub-station No. 3 the maximum load may be taken as occurring at 1:30 P. M., and results in approximately the same capacities as for sub-stations No. 1 and No. 2.

On sub-station No. 4 the maximum load may be taken at 12:15 P. M. The two cars, one starting and one running in the city, *J*, should be taken at one-half power because of the series operation of the motors during city running. The car at *I* will be starting and the car between *G* and *H* may be assumed to be running. Then the maximum load on sub-station No. 4 will be about $600 \div 1\,000\ [500 + (28 \div 100) \times 240 + (500 + 240) \div 2] = 570$ kw and the station capacity,

*Three cars each equipped with four 75 hp motors.

$570 \div 1.50 = 380$ kw. Checking by the rule and remembering that the city cars are half powered, the necessary capacity is $(4 \times 75 \div 2) + (4 \times 75 \div 4) + (2 \times 4 \times 75 \div 4) = 375$ kw. Because of the possibility of cars becoming bunched in the terminal *J*, sub-station No. 4 should be made of equal capacity with each of the other three sub-stations.

Unless the total sub-station capacity is small, say 300 kw or less, it should be divided into two or more units. Such sub-division of the apparatus permits of the operation of only part of the apparatus at times of light load, which results in a better load factor and better all-day efficiency. At such times the idle machinery serves as reserve capacity. Also the presence of several units increases the reliability of operation because, in case of accident to one machine, at least a partial service may be maintained with those remaining.

In the example cited above, each sub-station should contain two 225 kw units. Further consideration of the train sheet indicates that one of the units in each of the sub-stations, No. 2 and No. 3, may be held in reserve except on those days when extra local trains are in service. If single units are installed in each sub-station, spare capacity should be provided in the form of a portable sub-station. Also, in cases such as the foregoing example, where there is a reserve in only part of the sub-stations, it is well to install one unit in the form of a portable station. This should be normally located in either sub-station No. 2 or No. 3, where it could serve as one of the units required in that station, but would be available for use elsewhere in an emergency.

The total capacity required in rotating machines for any sub-station may be reduced by the use of storage batteries. In interurban systems the batteries serve to take the peak loads, thus reducing the overloads on the rotating machinery. They may be made of sufficient capacity to reduce the size of each rotating unit somewhat, but should not be used ordinarily to decrease the number of units in a sub-station. This is for the reason that the over-loads which make necessary additional station capacity continue for long periods (one, two or more days) so that an exceedingly large battery, capable of receiving approximately its full charge during the night hours, would be required to supply power for the increase in the average load during the day. Yet a relatively small battery can handle the load fluctuations, which are of short duration.

This limitation is often absent from city systems because the increase in station capacity for handling the rush hour peaks is liable

to be a smaller proportion of the total than the extra capacity for heavy days in interurban sub-stations and the durations of heavy average overloads is measured by hours instead of days. Hence in such cases it is frequently feasible to reduce both the number and size of the rotating units in a sub-station by installing a storage battery of such size that it is able both to take the momentary over-loads and to supply considerable power to the line during rush hours.

The selection of the capacity of battery necessary for taking momentary over-loads only, may be based on the train sheet. Having

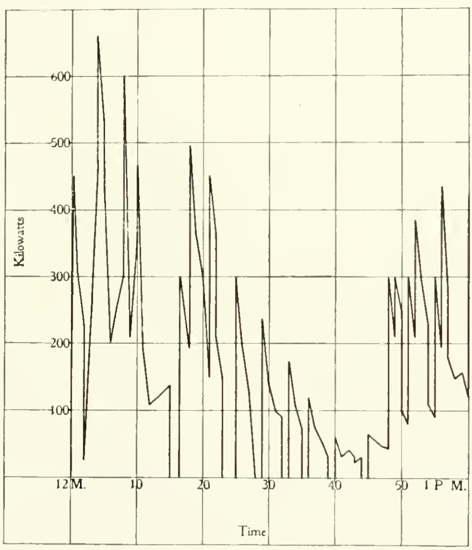


FIG. 2

determined the load which the rotating machines are to carry, a study of the train sheet will show the probable amounts of the over-loads and the frequency of their occurrence. In this connection a load curve is useful. The load curve for a station is constructed by estimating, with the aid of the train sheet, the load at various times, plotting these values on a time base and connecting consecutive points by straight lines. With a large number of cars or with definite stops, the actual curve may be very closely approximated. Fig. 2 shows an approximate load curve for sub-station No. 1, shown on the train sheet when regular stops occur at points 3, 4.5, 6.2, 8, 10, 11.6, 13.3 and 14.6 miles from the terminal in *A*.

When a battery is to carry the rush hour load, its capacity may be such that it will handle the increase in average load during rush hours with an allowance for the load due to momentary fluctuations. In all cases care must be taken to insure sufficient time for charging the batteries at a rate which will not be injurious and that the discharge rate will never be too great. No fixed law can be given by which it may be determined whether, in any specific case, it is advisable to use storage batteries. The decision in each case must rest upon a comparison of the advantages and disadvantages which will result in the particular case together with economic considerations. Some of the general advantages which may accompany the installation of storage batteries are, decreased total capacity in rotating machinery, uniformity of load on rotating machines, machines operating at better load factor and consequently better efficiency, and possibility of continuing service for a period in case of accident to the rotating machines. Some of the disadvantages of battery installations are, the large amount of space occupied, the inefficiency of transferring energy through storage batteries and the expense of maintenance. The last disadvantage is included because, while the rate of depreciation is small at first, it becomes very great when the plates begin to wear out and the average rate of maintenance and depreciation is, therefore, high.

The machines installed in the sub-stations for converting alternating current to direct current may be either rotary converters or motor-generator sets.* Generally the choice between the two types is in favor of rotary converters for interurban lines because of the smaller first cost and the fact that the transmission voltage is such that transformers must be located in the sub-stations in any event. The latter item results in much better total efficiency of the station with rotary converters. Where a low transmission voltage is used so that the motors may be wound for that voltage, no transformers are needed in the sub-stations and in such cases in cities the motor-generator set may be preferable to the rotary converter because it will require less space than a converter with its transformers and because of the possibility of better voltage regulation. Even on interurban lines, it may at times be best to use motor-generator sets, particularly if the transmission frequency is sixty cycles or higher.

Because of the difficulties attendant upon the operation of

*For an extended discussion on the relative merits of these two types of apparatus refer to the paper by Mr. P. M. Lincoln in the Trans. of the A. I. E. E., February, 1907.

rotary converters, connected in parallel on the alternating-current and direct-current sides, each rotary converter should be supplied from its own bank of transformers; or transformers with separate secondaries for each converter may be used. Separate transformers for each rotary are preferable unless all of the machines supplied from the separate secondaries of the same transformers are in practically continuous operation. The separate bank of transformers for each machine gives greater reliability and somewhat better all-day efficiency with intermittent operation of the machines.*

In addition to the rotating machines and transformers, the substation should be provided with switchboard; lightning protection for each high-tension line, whether entering or leaving the building; high-tension circuit breakers and disconnecting switches, and lightning protection on each trolley feeder.

HIGH-TENSION LINES

The transmission line should always be constructed with a view to its ultimate capacity. The first points to be determined are the voltage and size of wire to be used. This may be done conveniently by using the curves shown in Fig. 3†. No. 6 B. & S. gauge copper wire is the minimum size which is considered mechanically strong enough for use in transmission lines. At the higher voltages some engineers prefer to make No. 4 the lower limit. The maximum voltage to be used in particular cases may be determined by climatic or other local conditions. In any case nothing is gained by choosing a higher voltage than will be satisfactory with the smallest size of wire; for the first cost may be materially increased by such a choice because of the extra cost of higher voltage insulators and lightning protection. If the voltage is specified, the selection of the size of wire is comparatively simple. For example, 1 000 k.v.a., three-phase, at ninety percent power-factor may be transmitted twenty-nine miles at 20 000 volts with ten percent line drop by No. 4 B. & S. copper wire. This is found from the Fig. 3 as follows: The diagonal line marked 1 000 kw at the right is followed to the point where it cuts the vertical line passing through "29 miles" (at the bottom of the figure). From this point of intersection the horizontal line is followed to its intersection with the diagonal line

*The question of three-phase versus single-phase transformers is fully covered in papers by Mr. J. S. Peck and Mr. H. W. Tobey in the Trans. of the A. I. E. E. for April, 1907.

†These curves are calculated from the table and chart in an article on "Drop in Alternating-Current Lines," by Mr. Ralph D. Mershon, in the JOURNAL for March, 1907, p. 137.

marked 20 000 volts. From this latter point a vertical line is followed to the top of the figure, when it is seen that this line passes near size No. 4. Hence, No. 4 is the nearest suitable commercial size and will do the work with approximately ten percent drop.

Generally the problem is to determine both the size of wire and the transmission voltage. For small amounts of power and short distances, 22 000 volts is sufficient. A number of the smaller interurban roads will be found in this class. For a large number of the interurban roads which may be said to approximate the average

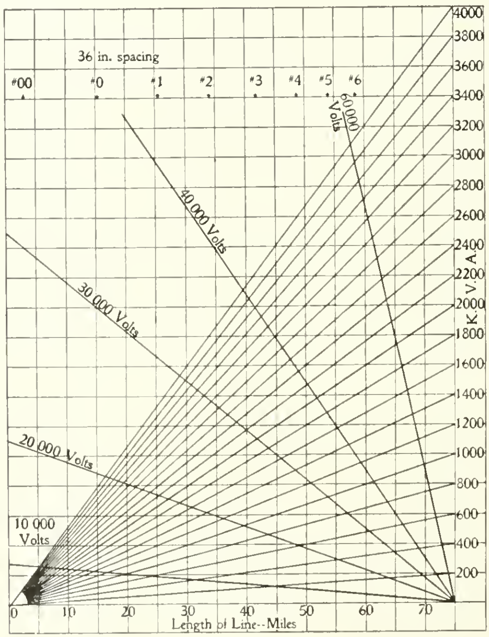


FIG. 3

interurban line of the present day, 33 000 volts will be found most suitable. Very large systems may justify the use of 44 000 volt transmission or higher. At the first trial, the problem may frequently be reduced to making a choice between two voltages. The final selection must be made by determining whether the saving in copper with the higher pressure will exceed the increased cost of insulators and protective apparatus with a balance to offset the additional risk of failure at the higher voltage.

The curve in Fig. 3 is made up for ten percent drop. With the usual ratios between average and maximum loads, the line

should be determined by limiting the drop rather than for any definite loss and a maximum drop of ten percent should not ordinarily be exceeded. With this maximum drop the average loss will usually be within five percent.

The wire sizes for thirty-six inch spacing between centers are shown, as this is the spacing most common with 22 000 volt and 33 000 volt transmissions. Other spacings could be worked out, but it is hardly ever necessary since very little difference in the drop is made by a change in spacing. The spacing of high voltage wires may be taken at one foot for each 11 000 volts. Ninety percent power factor is assumed as a fair average for a line supplying a mixed railway and power load.

Where the line feeds a single sub-station, the maximum load on the line is readily estimated by taking the maximum load used in determining the capacity of that sub-station and increasing it by the amount of sub-station losses in rotaries and transformers. It is very difficult, even with the aid of a train sheet to pick out the time and amount of maximum load on the transmission line feeding several stations. The several stations rarely have their maximum loads occurring at the same instant. One station may be heavily over-loaded, another taking average or full-load, a third carrying no-load, and so on. An average maximum load on the line may be obtained by assuming that each sub-station is drawing its rated capacity from the line. Interurban lines are usually of such length that it is unnecessary to use two or more sizes of wire in any one of the high tension lines, though the several lines may differ in size. Hence the average distance for the total load on a line may be found by averaging the several loads fed from that line in connection with the several feeding distances.

Referring again to the train sheet, Fig. 1, the load fed from the power house as far as sub-station No. 2 is 3 (450) or 1 350 kw; between sub-station No. 2 and sub-station No. 3, is 2 (450) or 900 kw, and from sub-station No. 3 to sub-station No. 4, 450 kw. The respective distances are nine, 8.8 and 8.8 miles. Then the feeding conditions are:

Between the power house and sub-station No. 2—9 × 1350 =	12 150 kw-miles
Between sub-station No. 2 and sub-station No. 3—8.8 × 900 =	7 920 kw-miles
Between sub-station No. 3 and sub-station No. 4—8.8 × 450 =	3 960 kw-miles
Total	24 030 kw-miles

This is equivalent to feeding the entire load of 1 350 kw three phase for a distance of 24 030 ÷ 1 350 or 17.8 miles. From Fig. 3

it is seen that this may be accomplished with No. 5 B. & S. copper wire at 22 000 volts.

For the sake of reliability, duplicate transmission lines may be installed. In determining whether duplicate lines are necessary where the load is small, and the transmission pressure moderate, the chief consideration is how much additional first cost may be assumed for the sole advantage of increased reliability. A single transmission line is adequate for the majority of transmission systems. Where the conditions are such that the size of wire for a single line becomes large, say No. 00 or greater, the necessity for reliability is usually great and sub-division of the line is further advisable because of the difficulties encountered with large wires and aerial cables. Sub-division is advantageous from an electrical standpoint because the inductance of the lines is reduced thereby.

The transmission line may be carried by cross-arms on the same poles which support the trolley construction and feeders or a separate pole line may be erected for the transmission wires alone. The first method is most common for interurban roads utilizing a pressure of not more than 33 000 volts. For higher voltages or heavy duplicate lines, the separate pole line is more satisfactory. Some recent installations have employed a type of wooden A-frame under the latter conditions. This has led to the proposal to combine the A-frame transmission line and the ordinary wood pole trolley line by replacing every third pole of the trolley line on tangents and alternate poles on curves greater than three degrees with an A-frame which will carry both trolley and transmission lines. This would give a cheaper construction than is possible with the separate lines and should be equally reliable.

The transmission line may be continuous or divided into sections. With the former type of line, the wires entering each sub-station are tapped into the line at a point outside of the station building. This method has the advantage of having only one set of high tension wires entering each building with only one set of protective apparatus and a minimum number of switches. If the line is to be sectionalized, it passes through each of the stations between the power house and the end of the line, the sectionalization being effected by switching apparatus within each station. The advantage of this scheme is greater reliability since in case of trouble on a distant portion of the line, the high tension circuit may be broken at the sub-station adjacent to the seat of the trouble on the power

house side and operation continued up to this point. The sectional transmission line is in general the better of the two arrangements because there is a considerable gain in reliability at small expense.

POWER HOUSES

The determination of generating station capacity is similar to that of sub-station capacity. The maximum load at the direct-current side of the sub-stations may be estimated on the basis of the probable number of cars starting and running. Adding to the value so found, the losses in sub-stations and transmission will give the load at the power house. A more convenient way is to allow one kilowatt of generator capacity for every two horse-power of rated motor capacity in car equipments. This rule is based on the fact that the continuous current capacity of a railway motor is about one-half of its rated one-hour capacity and that the average efficiency of a complete system well designed is about seventy or seventy-five percent from power house to car, so that if the motor is operating with a fair margin, one horse-power input to the car equipment is equivalent to one kilowatt output from the generator. Where conditions are such that a reasonably accurate load curve may be easily constructed, the generator capacity is best determined by its use.

The power house is frequently at a point along the railway line so that it is desirable to use it as one of the feeding points for direct current. In this case it is necessary to install in the power house itself machines for delivering direct current to the trolley and feeders. If the plant is so located that a large proportion of its total capacity must be furnished as direct current, it may be found advisable to install direct-current generators for that purpose and supply only the sub-stations from the alternating-current generators. When the amount of power supplied direct to the trolley at the power house is a small part of the aggregate station capacity, it is best to generate the entire load as alternating current and use rotary converters or motor-generator sets in the power plant. This is more economical than providing small separate generators for the direct-current load at the power station.

Very small lines may often be operated best from a single direct-current generating plant. In such cases, storage batteries and boosters may be used to good advantage for increasing the length of line, which may be fed from one point. A number of systems are in existence which have grown from one or more small lines, each

fed by a single direct-current power house with the result that an entire system is now fed by a series of direct-current power houses, each of small capacity. No new installations are being made on this basis. This situation is contrary to the general principle that in electrical generation and distribution of energy, the highest economy is effected by the concentration of the generating apparatus at a single point. Hence such systems are being gradually changed over to use a single alternating-current central station and alternating current distribution to alternating-current-direct-current substations.

The generating voltage in an alternating-current central station of the capacity required by the average interurban line should ordinarily be 2 200 volts. This potential permits of a most efficient design and is such that the wiring is less in amount than with a lower voltage without, on the other hand, involving expensive insulation. With very large generators, it will be found more economical to install 6 600-volt machines. If a system is such that a large proportion of the total power generated as alternating-current is to be converted through rotary converters into direct current at the power house, it may be possible, by winding the generators for the rotary voltage and thus avoiding the expense of and loss in lowering transformers, to save enough to more than offset the increased cost of station and switchboard wiring with the lower voltage. On the other hand, if the transmission voltage does not exceed 13 200 volts, the generators may be wound for the transmission potential. While this method increases the cost of the station switchboard, raising transformers in the power house become unnecessary and the total cost of the generating plant may be decreased. Where the power house feeds an aerial transmission line, there is an objection to winding the generators for the line pressure in that they are more subject to damage by lightning than is the case where transformers are interposed between the line and machine. This fact also forms an objection to the use of motor-generator sets in sub-stations when the motors are wound for the line potential.

For the sake of reliability the total power-house capacity should be divided between two or more units. A few isolated cases occur where the total amount of power is very small and capital is scarce, in which event it may be necessary to use a single generator in the power-house. For the average station, the best layout may usually be obtained by installing three or four generating units, one of which is a reserve unit at all times and possibly a second, which is in

use only during the daily periods of peak load. Limiting the number of generators to three or four units makes it possible to obtain the economy attendant upon the use of large units and at the same time affords a reasonable degree of reliability and flexibility.

For alternating-current generators it is, of course, necessary to obtain exciting current from a direct-current source of power. The exciters may be driven by separate prime movers, may be mounted on the end of the main generator shafts or may be motor driven. Of the three methods, the first is probably the best because it embodies the maximum degree of reliability in the minimum number of exciters. For any station, two exciters should be installed, each of sufficient capacity to supply exciting current for all the generators. While one of these machines is in use as an exciter, it is common practice to use a portion of the capacity of the other for lighting and shop power. The separation of the exciting and direct-current power circuits is readily accomplished through a double-throw switchboard.

The remaining power-house apparatus comprises raising transformers and lightning protection. In stations of moderate capacity, the generators may be paralleled through the bus-bars and the entire load to the transmission line fed through a single bank of raising transformers without involving excessive transformer sizes. In very large stations a bank of transformers may be provided for each generator. The switchboard may be one of several types depending upon the voltage and capacity of the plant. It provides panels for the control of the exciters—one panel for two exciters; one panel to control each generator; one alternating-current and direct-current panel for each rotary converter or motor-generator set, and feeder panels to provide for supplying current to the low-tension side of the raising transformers, for controling the high-tension lines and for feeding direct-current into the trolley. Lightning protection should be provided for each high-tension line and trolley feeder leaving the building.

METER AND RELAY CONNECTIONS—(Cont.)

TWO-PHASE AND FOUR-PHASE CONNECTIONS

HAROLD W. BROWN

Meter and relay connections for each phase of a two-phase circuit are in many cases the same as those for a single-phase circuit. In other cases, polyphase meters and relays are used in place of single-phase; in still other cases connections are made so that by changing the positions of plugs, meters are shifted from one phase to another. This shifting is not desirable, however, where it is practicable to use separate meters on the two phases.

TWO-PHASE FOUR-WIRE CIRCUITS

A group of meters is represented in Fig. 1 connected to a two-phase four-wire circuit. The phases are usually arranged in the order indicated in the diagram, where the first and third lines belong to one phase and the second and fourth to the other. Each phase is here provided with a voltmeter, ammeter, and static ground detector; there are also one frequency meter, one polyphase wattmeter, and one two-phase power-factor meter for the two phases. If it is important to measure the power and power-factor of the two phases independently, each of the polyphase meters may be replaced by two single-phase meters. Inasmuch as the frequency is the same on the two phases, only one frequency meter is required. With a group of meters such as is shown in Fig. 1, any form of overload relay should preferably be on a separate series transformer,* and would then be connected independently, according to the diagrams for that relay. For simplicity it is omitted from Fig. 1. Fig. 2 is similar to Fig. 1 except that, by inserting the plug on either side of the voltmeter receptacle, the voltmeter may be connected across the corresponding

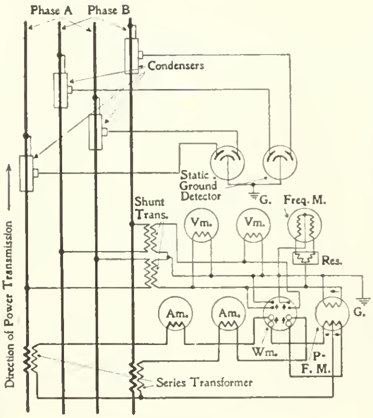


FIG. 1

*See reference to allowable load on transformers in the article on "Single-Phase Connections," in the Journal for October, 1908.

Note—All diagrams in this article represent rear view connections.

phase. When the ammeter plug is inserted in the left hand ammeter receptacle, the ammeter measures the current in phase *A;* when in the right hand receptacle, the current in phase *B.* The wattmeter measures the total power transmitted in both phases. In Fig. 1 the voltage circuit of the power-factor meter connects to phase *A* and in Fig. 2 to phase *B;* this makes no difference in the operation of the meter provided the left hand current circuit and the voltage circuit are connected to the same phase.

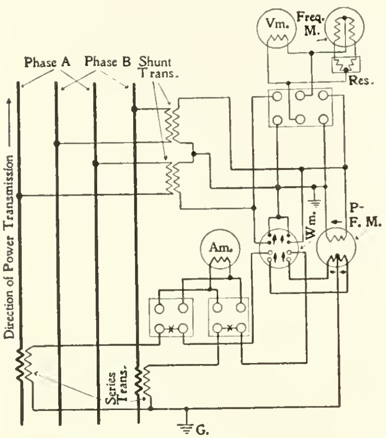


FIG. 2

Fig. 3 shows two single-phase power-factor meters and a polyphase wattmeter connected to indicate independently the power-factor and power on the two phases. The left and right hand power-factor meters measure the power-factors on the left and right hand circuits respectively. If a plug is inserted in only one receptacle the wattmeter measures the power transmitted by the corresponding phase. If plugs are inserted in both receptacles it measures the power transmitted by both phases.

The unbalancing of power in a two-phase circuit may be measured by connecting a polyphase wattmeter to the circuit in the ordinary manner, but reversing the current or e.m.f. connections on the left hand side of the meter, so that the left hand side tends to produce a negative and the right hand side a positive deflection. If the meter has a positive deflection it indicates that the phase connected to the right hand side is transmitting more power than the other phase. The inequality of the voltages of the two phases may be measured by connecting one phase to one circuit of a synchronizing voltmeter and the other phase to the other circuit. This instrument

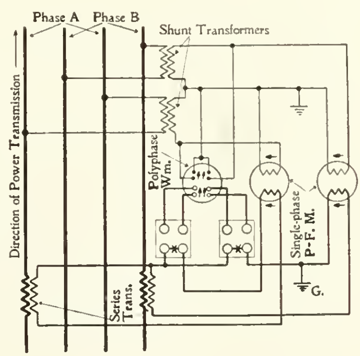


FIG. 3

consists of two voltmeter elements, one of which tends to deflect the pointer to the right, and the other to the left.*

TWO-PHASE THREE-WIRE CIRCUITS

Two-phase three-wire circuits have meter and relay connections in most respects the same as those for two-phase four-wire circuits. The series transformers are connected to the lines that are not common to the two phases. The primary connections to the shunt transformers are as indicated in Fig. 4. If it is desired to determine the current in the line common to the two phases it may be measured by means of the resultant of the currents in the series transformers on the other two lines.

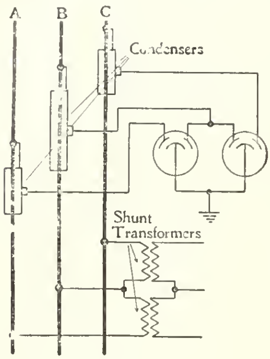


FIG. 4

The static ground detectors require a special condenser on line *B*, because this line is common to the two phases and this affects the e.m.f.'s between the several lines and ground as follows: The e.m.f.'s between lines *A* and *B* and between *B* and *C* are equal, and have a phase difference of 90 degrees; they may therefore be represented by *AB* and *CB* in Fig. 5. These relations do not, however, determine the e.m.f.'s between the three lines and ground; these e.m.f.'s depend on the insulation resistance and electrostatic capacity of the several lines. If the resistances are all equal, and the capacities are equal, the ground e.m.f. is at *G*, and the three vectors, *GA*, *GB* and *GC* represent the three e.m.f.'s between ground and *A*, *B* and *C*, respectively. The line *GB* makes angles of 45 degrees with *CB* and *AB* and is equal to 0.35 *AB* (its projection on *AB* is equal to ¼ *AB*). *GA* and *GC* are each equal to 0.79 *AB*. On account of the comparatively low e.m.f. from *B* to ground, the condenser on *B* must have a larger capacity than those on *A* and *C*, in order that the line *B* may have as much effect on the ground detectors at a lower e.m.f. as do the other lines at a higher e.m.f. Furthermore,

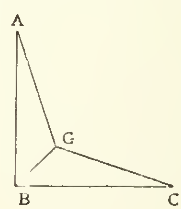


FIG. 5

*For the ordinary connections of the synchronizing voltmeter see Fig. 2 in the article on "Single-Phase Connections" in the JOURNAL for October, 1908.

both ground detectors are connected to the condenser on line *B*, so that this condenser must furnish the charge for the two ground detectors, whereas those on *A* and *C* furnish the charge for only one. On this account, also, the capacity of the condenser on *B* must be correspondingly larger than those on *A* and *C*.

TWO-PHASE FIVE-WIRE CIRCUITS

In two-phase five-wire circuits the fifth wire serves as a neutral in addition to the four wires ordinarily used. Instead of flowing out on one of the four lines ordinarily used and returning on the other of the same phase, the current on any line may return on the neutral wire. On this account the currents on the two lines of the same phase may be different, and it is necessary to have a series transformer on each of the four lines to make measurements on the entire circuit. Fig. 6 shows the connections for a polyphase wattmeter and a two-phase power-factor meter on a five-wire circuit. If the power-factor meter is omitted, the connections are completed as shown by the dotted lines. The meters and transformers must be especially adapted to each other, so that the sum of the secondary currents of two transformers is not too large a current for one wattmeter circuit; the calibration of the meter must be in accordance with these conditions.

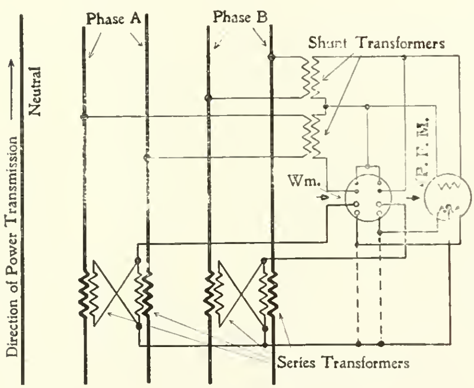


FIG. 6

As shown in Fig. 6, no connection is made to the neutral line. Instead of this arrangement, the voltage connections of each phase may be made from one line of that phase to neutral. The e.m.f. on the shunt transformers is then only one-half that across the line. A normal calibration of the meter with ordinary transformers is suitable for this case, because each current circuit of the wattmeter is fed by two series transformers instead of one, thus increasing the wattmeter current in proportion to the decrease in voltage; this, however, sends twice the normal current through the wattmeter. If the voltage from one line to neutral is not the same as from the other line of the same phase to neutral, this connection to neutral intro-

duces an error in the wattmeter reading; but, with the arrangement shown in Fig. 6, no error is introduced unless there is an unbalancing of both current and e.m.f., and even then it is likely to be very small. The former method of connection is therefore usually preferable.

FOUR-PHASE FOUR-WIRE CIRCUITS

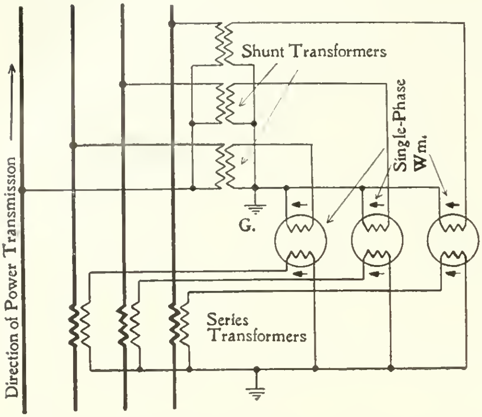


FIG. 7

The four-phase four-wire circuit is the same as a two-phase five-wire except that there is no neutral line. It is different from a two-phase four-wire circuit in that the two phases are inter-connected, hence a current may flow out on one line and return on any other. Connections may be made as in Fig. 6 with the neutral line omitted.

A method of connecting three single-phase wattmeters for measuring power on a four-phase circuit is shown in Fig. 7. The left hand line is arbitrarily considered as a return circuit, and the e.m.f.'s on the three wattmeters are the e.m.f.'s of the transformers connected from the left hand line to the other three lines. The wattmeter currents are those of the series transformers on these three lines. This method of measuring is independent of unbalancing of e.m.f. and current so long as the circuit is not grounded. Fig. 8 is similar to Fig. 7, but two of the single-phase wattmeters are replaced by a polyphase wattmeter, and a two-phase power-factor meter is added.* The power-factor meter indicates the power-factor

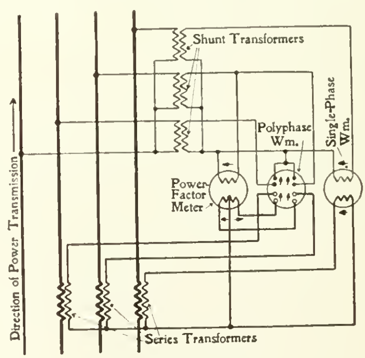


FIG. 8

*Connections similar to those in Figs. 7 and 8 may be employed for measurements on the two-phase five-wire circuit, by using four single-phase or two polyphase wattmeters. These measurements also are independent of unbalancing.

for only the two inner lines, but ordinarily this is practically the same as the power-factor for the entire circuit.

GENERAL

In some cases it is not at once apparent whether meters will indicate correctly with the simple two-phase four-wire connections, or whether the circuit should be treated as a two-phase, five-wire, or four-phase circuit. For example as in Fig. 9 if a two-phase rotary converter is connected to a two-phase generator whose phases are inter-connected at their middle (i. e., neutral) points, it is possible for the current to flow from the generator to the rotary converter on one line, and return on any of the other three lines; but if the two machines are perfectly balanced mechanically and electrically, there is nothing to deflect the current from the phase in which it started, and the two-phase four-wire connections give correct indications. If, however, there is a partial short-circuit or open-circuit in either machine, or any apparatus on the line connected between phases, the circuit must be considered as a four-phase circuit. If there is a ground return for part of the current, it must be considered as a two-phase five-wire circuit.

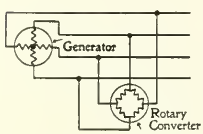


FIG. 9

In general these conditions may be stated as follows: If there are two or more grounds or two or more connections between phases, which would produce unbalancing of the currents in the two phases, the portion of the circuit between the grounds or inter-phase connections cannot be considered as a simple two-phase four-wire circuit, but the remainder of the circuit may be so considered. Where power transformers are used, as in Fig. 10, one ground or one connection between phases on the high-tension side, and one on the low-tension side of the system will not prevent its being treated as a two-phase four-wire circuit, for no current can flow from one phase to the other.

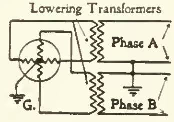


FIG. 10

In the case of two-phase to three-phase transformation, if the current and e.m.f. are balanced on the three-phase circuit they are also balanced on the two-phase circuit, and vice versa. The power-factors of the two circuits are also the same. These statements, however, do not take account of the slight unbalancing and phase distortion due to transformer losses.

EXPERIENCE ON THE ROAD

LATERAL ALIGNMENT OF A LARGE ALTERNATOR

E. L. DOTY

THE shafts of large turbine-driven alternators are usually connected to the shafts of the prime mover by means of flange couplings. The two halves of these couplings are very accurately turned to a given dimension. It is customary to "line up" the rotating element of the generator to the turbine. The two halves of the coupling must be in very close alignment before they are bolted together. With a generator having a rotating element weighing ninety or one hundred tons there will be an appreciable deflection in the shaft which makes it necessary to raise the outboard bearing of the generator in order that the two halves of the coupling may be parallel vertically. This may result in considerable end thrust toward the turbine when the generator is running with no current in the field, and there may be some end thrust when the machine is operating under the normal conditions of load if the lateral alignment of the stationery element is determined mechanically, as is ordinarily the case.

As it seemed possible, in a case with which the writer was connected, that this end thrust might affect the adjustment of the turbine thrust-bearing of a 7 500 kw turbine alternator set, the rotating element of which weighed ninety tons, it was decided to align the stator of the large generator laterally, by centering it electrically, after the halves of the couplings had been aligned, but with the coupling open in order that this alignment might not be influenced in any way by the turbine. The halves of the coupling, which are three feet in diameter, were aligned to within less than 0.0005 of an inch. This necessitated raising the outboard bearing of the generator about 3/64 of an inch. The stationary armature was moved out to such a position that the halves of the coupling would have ample clearance, and its position with relation to the bedplate accurately marked. This generator was connected electrically to a second generator of like characteristics by means of jumpers between the two generator oil switches. Full field for non-inductive load was given each generator, and the turbine driving the second generator was brought slowly up to approximately full speed, operating as a synchronous motor. The field of the generator at once centered itself and operated with extreme steadiness. The opening between the

two halves of the coupling was carefully measured, and this measurement was checked after shutting down the generator with the field on. The armature was then moved a definite distance toward the turbine and its new position accurately marked. The generator was again operated as a motor and the opening in the coupling was carefully measured in order to check our first measurements.

To obtain an absolute lateral alignment it was now only necessary to move the armature towards the turbine a distance equal to the measured distance between the two parts of the coupling.

A WATER RHEOSTAT USED IN TESTING A 2200 VOLT GENERATOR

W. L. DURAND

In testing power plants it often happens that the character of the station load is such that it will not furnish the conditions required for a given test. It is then necessary to fall back on

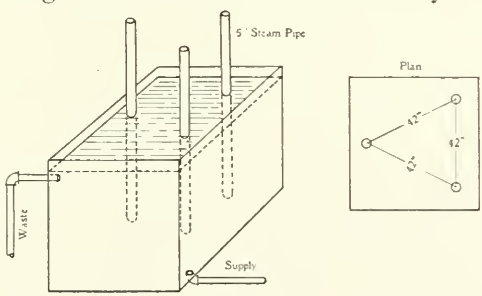


FIG. I

some auxiliary means. In a recent test of a power plant containing two three-phase 50 cycle, 2 200 volt, alternating-current generators belt-connected to Corliss engines, the contract called for a separate test on each unit at a load of 225 kw. As the regular station load was then only about 125 kw, it was decided that a water rheostat would be the most satisfactory means of supplying the additional load required. There was no one available who had had any experience with water rheostats, but everyone contributed his ideas, and the rheostat, when completed, did all that was hoped for it. The details and dimensions may prove useful to some one meeting with a similar condition and not knowing any more about water rheostats than we did.

The general layout of the rheostat is shown in Fig. 1. A box, five feet in all dimensions, was made out of one inch pine

boards and caulked to make it water tight. This was placed on the ground under the window nearest the switchboard. A three-fourth inch pipe was run from the city water system through the bottom of the box at one side and near the top on the opposite side an inch drain pipe was placed. A cover with three holes at the corners of a 42-inch equilateral triangle was fastened on the box. In each hole was placed a five-foot piece of five-inch pipe to one end of which had been soldered a heavy copper wire loop. Each wire was connected to one side of the three-phase circuit by an insulated wire running from the back of the switchboard to the pipe. The pipes were raised and lowered by means of ropes fastened through insulators to the wire loop on the pipes, and running in pulleys held by a temporary frame work. The ropes were carried through the window into the power house where they were fastened. During the test the pipes were raised and lowered until the proper load and phase balance was obtained. To determine this a wattmeter was so connected that the load on any phase could be read. Throughout the whole test the rheostat worked with entire satisfaction, and the closeness with which the load was regulated may be judged by the fact that the average load for the whole test was 226 kw.

INTER-CONNECTING THE WINDINGS OF TWO-PHASE GENERATORS

G. W. CANNEY

Unexpected and apparently misleading results are sometimes encountered when testing newly installed apparatus or making changes in apparatus which has been in service. A case of the latter kind recently occurred when an attempt was made to obtain 0.7 normal voltage from a 40 kw two-phase 440-volt revolving field, engine type generator for use in starting induction motors. The machine had a winding which could be inter-connected to give the lower voltage, and the motor-starting devices had been connected up with a view of using the side circuits for starting. The first attempt to start a motor disclosed the fact that there was no voltage across the side circuits and on invesigating it was found that the middle points of the phases had not been connected together. As the machine was of the stationary armature type and the windings could easily be followed, it was apparently a simple matter to make the connection be-

tween the phases. This connection was made and the machine started. Voltage readings across the main and side circuits were taken to check the accuracy of the work. The results were not what had been expected, as the readings indicated that the taps were not in the electrical center of the phases. With the generator voltage at 297 across both phase A_1A_2 and B_1B_2 the voltage across the side circuits A_1 and B_1 was 236; across B_1 and A_2, 211; across A_2 and B_2, 186, and across B_2 and A_2, 211. These readings indicated a badly unbalanced condition.

Voltage readings were next taken between each armature terminal and the connection which had been made between the phases. With the generator at 347 volts the following results were obtained: A_1 to connection, 193 volts; A_2 to connection, 154 volts; B_1 to connection 193 volts; B_2 to connection, 154 volts.

Next an attempt was made by use of a needle pushed through the insulation, to locate the points in the windings which would give equal voltage to each terminal. This test indicated that the taps should be about eight turns from the center of each phase. To make such connections it would have been necessary to tap the inner layer of the winding and which would have been a difficult operation. As the phases had been connected together at their exact mechanical centers and there were no reversed coils, it seemed obvious that the results obtained were due to the generation of a higher voltage in some coils than in others. It was further observed that the sections of winding which gave the highest voltage readings were all on the same side of the machine. This fact suggested an unequal air-gap and upon taking measurements, the side of the armature upon which the high voltages had been obtained was found to be nearly one-thirty second of an inch closer to the field than the other side. As the total air-gap was small, this difference was sufficient to cause the results obtained. After properly adjusting the air-gap, the voltages balanced as closely as could be read on the voltmeter.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly. If a personal reply is desired in advance of publication a stamped return envelope should be enclosed.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

161—Unbalancing of Armature Currents Due to Unequal Air Gaps—In the answer to Question No. 54, in the May, 1908, issue, it is stated that in a two-circuit winding, the current will divide unequally between the brushes if the air-gaps are unequal. I understand that in this type of winding the conductors of each circuit are uniformly distributed under all poles. If this is correct, e.m.f.'s less than normal will be induced under those poles having the larger air gaps. But half of the conductors belong to one circuit and half to the other. The effect, therefore, is the same on both circuits. The only thing remaining, which might be thought to produce inequalities in current is the fact that between two brushes of the same polarity there is one armature coil which serves to connect them in parallel. This coil, at the moment of commutation, is in a weak field, and has only a few turns in it, so that any e.m.f. induced in it, whether, air-gaps are equal or unequal, must be small. From this, I would say, there is nothing to cause the current to be divided unequally between the brushes. It is also stated that in multiple windings, the cross-connections serve to equalize the pole strengths in spite of unequal air gaps. If there is any such effect, it would appear to be due to the unequal armature reactions under poles having unequal air gaps, resulting from the unequal currents in the several circuits, and not in any way due to the action of equalizer rings. The function of equalizer rings is to equalize currents in the commutating zone only, and not in the active working coils under the poles. In this way they prevent sparking, but simply by providing a path for the cross-currents which would otherwise flow through the brushes. These cross currents are free to flow through the cross-connections from only those coils in which at a given instant, little or no e.m.f. is being generated, and hence they are effective only when the coils they connect emerge from under the poles. This in no way corrects inequalities in the active coils themselves. C. A. B.

Our answer to this question was not entirely correct and the criticism referring to two-circuit windings is well taken. Since the conductors in each circuit are uniformly distributed under all poles, unequal air gaps and pole strength can have no effect on the total voltage generated in each circuit. Referring to that portion of the question relating to multiple windings, we believe our answer as originally made to be correct and the above explanation to be wrong. Whatever explanation may be offered for the action of the cross-connections must take into account the fact that a multiple-wound, direct-current armature without cross connections can have an unbalanced magnetic pull due to differences in air gaps under various poles. In early direct-current generators, before cross-connection were used, it was necessary to figure on this unbalanced magnetic pull. In some cases excessive un-

balanced magnetic pull was compensated for by adjusting the number of ampere-turns on the various poles. On the other hand, with cross-connecting rings, this unbalanced magnetic pull disappears. The sparking at the brushes that accompanies unbalanced magnetic pull also disappears. It is, of course, possible to explain these facts in different ways and it may be that the criticism takes into consideration the above facts. The correctness of the explanation, however, is not apparent. We believe the action with cross-connections in multiple windings to be as follows: The cross-connections connect points in the winding that are normally at the same potential. With unequal air gaps these points in the armature winding that should be at the same potential are at different potentials, and this difference in potential causes currents to flow through the cross-connections and through the adjoining armature coils in such a direction that the difference in potential disappears. Thus, the path of the cross currents is not necessarily limited to the cross connections from coils having little or no e.m.f. generated in them, as suggested above. They can flow in any coils included between cross-connected points in the armature winding, which, due to abnormal conditions, are at different potentials. F. D. N.

162—TRANSFORMER CONNECTIONS—Three power transformers, primaries in series, secondaries in parallel, give 110 volts secondary. Disconnecting any one secondary lead causes a large decrease in the voltage. Please explain. F. H. G.

With the three transformers connected as indicated the effect of disconnecting one of the three parallel secondary circuits would be to thereby remove from this transformer its share of the load. The primary winding of this transformer would then act simply as a choke coil. On no load this would not materially effect the voltage; however, with transformers loaded there would be a large impedance drop in the primary winding of the transformer having the secondary open-circuited, which would result in lowering the effective secondary voltage, thus accounting for the conditions noted. C. B. G.

163—In the article on "Alternating-Current Potential Regulators" in the August, 1908, issue of the JOURNAL, the text explaining Figs. 1 and 2, p. 450, does not agree with the conditions as represented in the figures. The statement is made that Fig. 1 shows the regulator raising the feeder voltage 10 percent at the same time reducing the current in the same proportion. Would not the current be *raised* 10 percent instead of *lowered*, and would it not be more consistent to make the calculations on this basis than to figure the different effects to a basis of 100 amperes on the bus leads? The same criticism applies to Fig. 2 in which the feeder voltage is lowered 10 percent and the current raised in proportion. T. W. V.

The figures in the original article mentioned in this criticism are correct. The difficulty in mind is due to their being considered from a different point of view than that in the text. In the latter, constant kilowatt output of the generator is assumed, it being the endeavor simply to show the relation of the current and voltage on each side of the regulator. If it is assumed that the load on the feeder and consequently the load on the generator, varies with variations in voltage the current and voltage relations in the circuits would then differ from those represented in the figures. Either point of view is correct. G. R. M.

164—SHORT-CIRCUITS IN INDUCTION MOTORS—Please tell me how the windings in the stators of induction motors are tested for short-circuits. H. P.

If there is a pronounced short-circuit in any one of the phases it may show up in the resistance readings since, if a portion of one phase is cut out, the resistance of this phase will be low. Another test which is sometimes used before the rotor is assembled in the stator is to apply a low

alternating-current voltage to each phase in turn. Unbalanced current would indicate trouble, providing the winding has the same number of turns per phase. Unbalancing, however, in either of these tests may be due to a portion of the winding having been cut out entirely, or the wrong size of wire having been used in a portion of the winding, or due to there being a difference in the number of turns per phase. Upon the application of a proper voltage, after the machine is assembled and in running condition, a short-circuit is readily discovered by localized heating. If convenient, a lower voltage may be used; if this is not at hand, care should be taken not to overheat the short-circuited portion of the winding, in case any such should develop. More elaborate tests require special apparatus. M. W. B.

165—POWER-FACTOR IN TRANSMISSION SYSTEM—In an interconnected transmission system in which there are two generating plants one of which is six miles, and the other twenty miles from the center of distribution, it has been found that the power-factor at the plant six miles distant is 55 percent, while at the other the power-factor is 91 percent. Please explain this. What is usually done to overcome such difficulty and equalize the power-factor? A. E. S.

The difference in power-factor which you note is due to a difference in the strength of the field current in the respective generators rather than to difference in the distance of the two balanced generating stations from the load. See also Questions and Answers 78, 126-7-8-9 and 142. H. M. S.

166—GROUND CONNECTION ON RAILWAY MOTORS—In a single trolley system, which is preferably to be connected to ground, motor armature or field, and why? J. I.

In a 500-volt motor, the drop in the series field winding is about 40 or 50 volts at full-load. If the ground connection is made on the armature side of the motor circuit both the armature and field circuits should be insulated for full line potential, whereas, if the ground connection is made on the series field side of the motor circuit there is nearly full potential to ground on the armature but only 50 volts to ground at full-load on the field. Where the armature is grounded it is claimed that the field winding protects the armature against lightning disturbances from the line. It is also claimed that the tendency to "buck over" is somewhat reduced by this arrangement. However, probably 90 percent of the motors are connected with the field circuit on the ground side. It will be observed that with this arrangement the control circuit of the motor is arranged so as to reverse the armature circuit when the direction of rotation of the motor is to be reversed. H. C. K.

167—BUTT JOINT CORE TYPE TRANSFORMERS—In repairing some 60 kw, 22 000/2 200-volt core type transformers, it was observed that the sheet steel laminations forming the cores were held together by bolts and the ends milled off to form butt joints with the yokes, the latter being centered on the cores by wooden dowel pins and clamped in place by heavy bolts. In one of these transformers paper insulation, about 0.015 inch in thickness had been inserted in the four butt joints between the ends of the cores and the yokes. In other transformers of the same type no paper was used and the dowel pins were of iron instead of wood. Why should the manufacturers attempt to insulate these joints? Should not a magnetic circuit be as complete and continuous as possible? O. B.

This construction, using butt joints with paper insulation inserted therein is referred to and explained in a discussion, at the Chicago A. I. E. E. meeting of May 4th, 1907, of Mr. J. S. Peck's paper on the "Relative Merits of Three-Phase and Single-Phase Transformers," in connection with the subject of High Tension Transmission. This reference will be found in the November, 1907, A. I. E. E. Transaction, p. 1614. The ref-

erence to this construction is as follows:

"The butt joint between the yoke and the rest of the core can only be satisfactorily made if the surfaces that are to come in contact are milled or otherwise finished to a true surface. If the surfaces are not finished, or even if they are, the eddy currents between the sheets in the two parts of the core may readily be sufficient to cause the welding together of the laminations. Some manufacturers use thin sheets of paper between the two parts of the core to avoid this, but the thinnest paper results in a material increase in magnetizing current." E. C. S.

168—INTERPOLES ON COMPOUND MOTORS—Please explain the operation and action of interpoles applied to direct-current compound wound motors. O. J. C.

The operation and action of interpoles on compound motors are the same as for shunt motors, viz., of providing a commutating field, the strength of which varies with the armature current and which opposes the reaction of the armature on the field, producing a fixed neutral point under varying loads and under varying speeds obtained by adjustment of field current. It is sometimes necessary to start a motor by throwing it directly on the line without the use of starting resistance. In such cases the motor is usually made compound wound and interpoles are used to furnish a commutating field; these prevent the motor from bucking or flashing seriously at the brushes under the rush of current when the starting switch is closed. F. A. R.

169—VOLTAGE AND SPEED VARIATIONS—Does variation in the speed have less effect on the voltage of a compound-wound generator than on that of a shunt wound machine? Is the speed of a shunt wound motor affected more by voltage variations than that of a compound-wound motor? If so, about how much? W. O. M.

The relation between voltage and speed in compound-wound generators and motors is such that the variation in one factor causes an approximately proportional variation in the other. There is little difference in the shunt and compound machines in this respect; although variations tend to be cumulative in the compound-wound machine due to the effect of the series winding. C. F. L.

170—DISCHARGE RESISTANCE FOR FIELD COILS—A three hp, 500-volt, 1 000 r.p.m., direct-current motor is provided with a solenoid which may be connected in multiple with the field coils of the motor. When so connected would each coil tend to dissipate the counter-e.m.f. of the other, or would they tend to combine and increase the total discharge voltage in proportion? If so, what is the pressure of the counter-e.m.f. of discharge from the fields of a motor of this size? A. E. W.

Each coil would serve as a discharge path for the other upon the opening of the line connection; so long as the circuit of the coil itself is not opened, the counter-e.m.f. is not large, so that no discharge effect need be looked for. The pressure of the counter-e.m.f. of discharge from a coil excited from a given line voltage and suddenly opened without a discharge resistance or other metallic circuit connected in parallel with it, is directly proportional to the number of turns in the coil; the number of amperes exciting current before the circuit is interrupted; the area of cross-section and permability of the iron core, and the suddenness with which the circuit is broken. In order to calculate the exact counter-e.m.f. of discharge it would be necessary for you to determine these quantities. The formula for determining this may be found in text books on Physics, on Induction Coils or on "The Elements of Electricity." H. C. N.

171—SPEED ADJUSTMENT OF DIRECT-CURRENT MOTOR—It is desired to reduce the speed of a 1 600 r.p.m. reversible motor to 975 r.p.m. Is it possible to do so without requiring the purchase of a speed regulator? The motor is a compound-wound machine designed for 23 amperes at 110 volts and is used to operate a printing press. A. F.

In order to effect satisfactorily such a speed reduction, a motor especially designed to give speed adjustment by means of field control would be required. From the information given it is understood that this motor is not so designed. Reduction of speed could be accomplished by the introduction of resistance in series with the armature circuit; this, however, is not an economical or satisfactory means of speed reduction. This would require not only resistance grids but a means of cutting them in and out of the circuit, *i. e.*, a controlling device. The most advisable move would be to confer with the manufacturers of the motors or some reliable manufacturer of motor controlling devices with an idea of obtaining a means of speed control such as is desired.

H. D. J.

172—Direct-Current Motors for Printing Machinery — Please give method of determining the exact size of motor for use as a means of individual drive for such machines as printing presses, folding machines, ruling machines and pamphlet trimmers, which are at present operated from a line shaft. Are shunt or compound motors to be recommended for this work? H. M.

The only exact way of determining the amount of power required by a given type of machine is to insert between the load and the source of power a device such as a dynamometer to measure the power during the cycle of operation of the machine. If the machine gives a peak load at one or more intervals during the cycle of operation, a compound-wound motor is required to supply the necessary torque at the instant of peak load, this load and its duration determining the size of motor required. A fly-wheel may be used to take care of such peaks; in this case the speed characteristics of the compound-wound motor are such as to give a drop in speed as the load increases, thus throwing the load on the fly-wheel. The following data obtained from measurements made in actual tests of various types of printing and binding machinery may be of value as a guide to the selection of motors for the electric drive of the machines. Folding machines require shunt wound motors of from 1/3 to 2 hp, depending on size; ruling machines require shunt-wound motors of from ½ to 1 hp; combination rulers and perforators may require 1.5 hp; pamphlet trimmers require compound-wound motors of from ½ to 2 hp for the simple types and 3 hp or more for the duplex types; cutters of sizes from 30 inches to 84 inches require compound-wound motors of from 1½ to 5 hp capacity. The size of motor required for printing presses depends not only upon the size of machine but also upon the type and the characteristics of the cycle of operation and the number of impressions made simultaneously. High speed newspaper presses of the rotary type, making several impressions and automatically folding the paper, require motors of from 75 to 90 hp capacity and possibly even larger motors for the extra heavy duty types. The load is of such a nature that shunt wound motors are most desirable. A rotary press having a frame 12 by 39 inches and giving a single impression requires approximately a 3 hp shunt-wound motor. Cylindrical presses giving one impression require compound motors of from 2 to 6 hp capacity; two-color presses of this type require motors of from 10 to 15 hp capacity, depending on the cycle of operation. Platen job presses having fly-wheels of ample size may be operated satisfactorily by 1 200 r.p.m., shunt motors of from ¼ to 1 hp capacity, depending on the size of the press. The motor should be belted to the fly-wheel. The output may be increased from 15 percent to 25 percent by the use of variable speed motor drive. It is found by experience that the power required when using motor drive for job presses will average 40 percent to 60 percent less than that required for drive by means of shafting and belts. L. B. B.

173—Rewinding Induction Motor Compensator—In rewinding a 2 000-volt compensator, used for starting an induction motor of the squirrel cage type, which it is desired to use on a 4 000-volt circuit, what size wire and number of turns should be used? H. M.

Wire of one-half the size should properly be used with twice the number of turns in the coils. It is necessary to double the number of turns because the voltage is twice as great. For the same capacity doubling the voltage decreases the current one-half; hence wire of only one-half the size used at present is required. It may be found difficult to get twice the number of turns of wire of one-half the present size in the given space, as for a given weight of wire there is a greater amount of insulation on the smaller size of conductor. If the compensator is of ample capacity for the particular service to which it is applied it may be found satisfactory to use say 190 percent of the present number of turns in case it is found difficult to get the proper number of turns in place.

E. E. L.

174—Leading Current in Synchronous Machines—By over-exciting a synchronous motor a leading current is introduced into the supply line and the power-factor is raised. Why does over-exciting the synchronous motor cause a leading power-factor? In the case of a synchronous converter why is it considered necessary to put reactance coils in the supply line? Is it done so that, when the fields are over-excited, a leading current will be introduced into the supply line? Why is it necessary to use reactance coils with a synchronous converter and not with a synchronous motor? How does the self-induction of the supply line affect the case?

H. L. S.

In a synchronous motor the magnetization is determined by the impressed voltage. It is maintained at this constant value (constant because the impressed voltage is constant) as a result of the combination of the exciting current in the field coils with exciting currents in the armature winding. If the exciting current in the field coils is not sufficient to set up the magnetization required by the impressed voltage, the phase of the armature current will change so that the armature current will supply the necessary additional magnetization. In this case the current required in the armature must be leading with respect to the induced voltage of the synchronous motor and is therefore lagging with respect to the generator or impressed voltage. Insufficient excitation, therefore, causes a lagging current in the line, and likewise, over-excitation causes a leading current in the line, relative to the generator voltage.

Reactance coils are used with a synchronous converter, in order to cause an increase in the impressed voltage when the fields are over-excited by the main direct current in the series winding. This increase in impressed voltage causes a corresponding increase in direct-current voltage. The reactance coils are, therefore, a necessary part of the voltage compounding of the synchronous converter. It should be noted that these reactance coils are not the cause of the leading current in the supply line, but make use of this leading current to raise the impressed voltage. Reactance coils are not used with synchronous motors because there is no reason for raising the impressed voltage of the synchronous motor as there is in the case of the rotary converter. Self-induction in the supply line has the same effect as the reactance coils.

F. D. N.

175—Synchronizing Rotary Converters With Reactance and Starting Motor—Please explain method of synchronizing rotary converter by use of starting motor and reactance coils. What are the connections? Why would not resistance serve the same purpose? Is this method applicable to synchronous motors? If not, why?

C. H. B.

When a rotary converter is started by means of a starting motor and reactance coils, the purpose of the reactance coils is simply to obviate the necessity for careful synchronizing. The rotary is started by a starting motor in the usual way, and when a speed above synchronous speed is reached the starting motor switch is disconnected and the alternating-current side is connected immediately, to the line through the re-

actance. The resulting armature current causes the rotary to lock in step when the speed drops to synchronous speed. The connections differ from standard connections using a starting motor only in having the reactance in series with the main leads and the in series with the main leads and special main switch by means of which the reactance coils can be connected in circuit and then short-circuited. Reactance is better for this purpose than resistance because a larger current is required to hold the rotary in step when resistance is used than with reactance; moreover, resistance in circuit tends to produce hunting while reactance does not. This method of starting is equally adapted to synchronous motors. There is not, however, the same reason for its use with synchronous motors on account of the absence of the commutator in the synchronous motor. In the rotary converter, started from the alternating-current side without a starting motor, the starting current is sufficient to cause flashing at the commutator, especially when low resistance dampers are used. For this reason the starting motor and reactance method for starting rotary converters is preferable to self-starting, as far as operation is concerned. The larger starting current required for self-starting is not objectionable with synchronous motors in the majority of cases; this method is, therefore, feasible and is less expensive in first cost than the reactance and starting motor method. F. D. N.

176—Recording Demand Wattmeter—For what purpose is a recording demand wattmeter used and is it connected the same as an ordinary wattmeter? H. P.

Recording demand wattmeters are used to make a record of peak loads at regular intervals, that is they record the largest number of watts measured in each minute or each hour or other period of time. This record is used as a basis for the charge for electric power. This type of meter is not of the same construction as indicating or integrating meters and the connections are different and vary with different meters. H. W. B.

177—Graphic Recording Meter Connections—Will the graphic recording wattmeter and the power-factor meter shown in Fig. 177(a) register correctly (with commercial accuracy) when connected as shown? F. H. G.

Yes; this is a standard method of connection except that the control circuit of the graphic recording wattmeter is connected to the same shunt

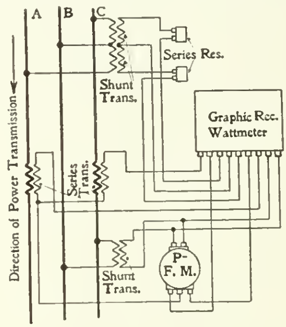


FIG. 177 (A)

transformer as is the potential circuit of the power-factor meter. No error is introduced unless the transformer is thereby so overloaded that its secondary e.m.f. is excessively reduced. This, however, is altogether improbable. H. W. B.

178—Auto-Transformer Rating—It is desired to supply a 120-volt, three-phase, lighting load of 30 kw from a 240-volt circuit, distributing the lighting load from a three-wire panel. The present load on the 240-volt circuit consists of three-phase, 60-cycle induction motors. Can the required voltage for the lighting load be obtained by the use of a compensator, and what will be its cost? How is the capacity of the compensator calculated? R. P. H.

The rating of the auto-transformers is determined by the amount of the low voltage load, namely, 30 kw. Assuming that the load is approximately balanced, three 10 kw auto-transformers connected in "star" will be required. For prices, inquiry should be made of the manufacturers of such apparatus. H. M. S.

THE

ELECTRIC JOURNAL

VOL. V. DECEMBER, 1908 NO. 12

Shop Opportunities

The article by Mr. Auel on "Some Opportunities on the Shop Side of the Engineering Industries," in this issue of the JOURNAL, is an important and timely contribution, setting forth, as it clearly does, the many sided opportunities and lines of progress open to those young men, both technically educated and otherwise, who persistently follow the training possible in the workshops of our great industries. The picture is under, rather than over-drawn, for aside from the chances of development and training afforded for occupations and business opportunities pointed out, in these great bee-hives of ceaseless human effort and complicated organization, as nowhere else, does a young man have so many possibilities, not only to observe, but to participate in executive and administrative work.

Executive ability, the ability to administer affairs and do things through organization, is one of the rare faculties and attainments of men, and is compensated perhaps more highly than any other quality in men of affairs. This ability is natural in some gifted persons, but can also be developed through experience and training, and for such development there is no better school than a busy workshop.

The long hours on duty necessary in occupations connected with shop work are cited as a detriment to ambitious young men from engaging in this work. This and other objections would, we believe, be largely overcome did those in authority give more enthusiastic support to young men starting in a career based upon shop experience. Through lack of ability to see far enough into the future, but with a keen sense of the limited outlook from the point of view presented to him (and this is very real to those in most shop positions), many an ambitious man with good qualifications has been discouraged and given up, when an encouraging word of advice and guidance from one who had been through such experience would have caused him to complete his training.

By this is not meant pampering or relieving the boys of the hard knocks and difficulties incident to their proper training and de-

velopment (for without these little real progress is made, as we grow strong only by overcoming difficulties); but merely such wholesome interest and suggestion as one in a preferred position can give with value to others struggling to its attainment. E. M. Herr

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Standard Apparatus for Special Conditions

Ingenuity, together with a knowledge of the principles of operation and the limitations in the performance of standard electrical apparatus, may often lead to its adaptation to unusual or special cases which involve more or less variation from normal or standard conditions. By changing some of the conditions of operation, quite unexpected results can often be secured without taxing the apparatus. Caution is necessary, however, for there is always a liability of exceeding the safe limit in some direction, such as insulation strength, temperature or regulation, a matter which is apt to be overlooked in laying out a novel scheme. In general the three elements above mentioned are essential.

Ingenuity is necessary. Sometimes the new arrangement is intricate or complex, but often some simple way is discovered of meeting an emergency with apparatus at hand by applying it in an unusual manner. When the plan is carried out, it is usually perfectly obvious; very often commonplace things, which are most obvious after somebody else has done them, are the most difficult things to discover.

Next, there must be a knowledge of the principles upon which the apparatus operates. Quite unexpected results may follow the endeavors of the merely ingenious man when he attempts to couple circuits of different phase relation in parallel, or to run a large 110 volt motor and a small one in series on a 220 volt circuit.

Further, it is necessary to know something of the allowable variations from the conditions of normal performance in the particular apparatus involved. The limits may be saturation, temperature, speed or some other element. In some apparatus an excess of twenty-five percent may be inadmissible, while in other cases one hundred percent may do no harm.

The method of transforming from a three-phase to a two-phase circuit by means of standard transformers, as described by Mr. Starrett in this issue of the Journal, is an admirable illustration of the application of ordinary apparatus for an unusual pur-

pose. The arrangement is ingenious. The combination is out of the ordinary. We all see it now; very few of us would have thought of trying, even in an emergency, to adapt standard transformers to meet so uninviting a requirement as 4 000 volts and 86.6 percent of 4 000 volts. But the man who devised this arrangement had been in a transformer testing department for several years and had learned something of the adaptability of the transformer, so he set about to work out a proper combination.

It was necessary to be familiar with the fundamental principles of the transformer in order to know what theoretical arrangements would be operative. It was essential to know that transformers can be operated with their primary windings in series and their secondaries in multiple when the characteristics of the two transformers are identical, and also when one of them is adapted for twice the primary e.m.f. of the other. It was also essential to know the conditions under which two separate transformers, each having half the e.m.f. of the circuit, may be used in the place of the single main transformer in the T-connections for transforming from three to two phases. A theoretical and practical knowledge of the elementary principles of the transformer was, therefore, necessary for the solution of the present problem.

The third element which is usually necessary in the adaptation of standard apparatus to special conditions is a knowledge of the variation from normal conditions which is permissible. In the present case, part of the transformers are to operate at five percent above their normal voltage. This increase is so slight that there is practically no question involved. If, however, a considerably greater increase had been necessary, the probable results of such increase should be known. An engineer thoroughly familiar with transformer practice would know that an efficient transformer for 60 cycles would in all probability be designed for a fairly low induction which would permit of a considerable increase in voltage without exceeding reasonable saturation limits in the iron. There would, of course, be an increased iron loss which would probably be permissible especially if the transformer is not in continuous operation or if the copper losses under the proposed operation are less than normal. On the other hand, he would know that an autotransformer, used for starting an induction motor, is probably designed to operate at high induction, so that a considerable excess of e.m.f. would be out of the question. He would likewise know that transformers for low frequency circuits are probably operated at

high induction, so that a considerable increase in voltage would not be allowable. Again, he would apply a low frequency transformer to a high frequency circuit with impunity, but would hesitate to use a high frequency transformer on a low frequency circuit, except with caution, or at a reduced voltage.

In the instance under consideration, another practical point was involved, namely, the fact that a difference of five percent voltage between the two phases does not lead to discomfort in the operation of two-phase motors.

It would be quite ill advised to propose the general use of standard apparatus under abnormal conditions. It often happens, however, that a proper combination of ingenuity and theoretical and practical knowledge will enable standard apparatus to be applied with entire success both for special requirements when new work is being laid out, and also to meet emergencies which occur in ordinary operation.

CHAS. F. SCOTT

Arrangement of Train Sheets

In the articles on "Electric Railway Engineering" by Mr. F. E. Wynne in the October and November issues of the JOURNAL, reference is made to train sheets and, in connection therewith, to an article on that subject, written by the undersigned, which appeared in the Street Railway Journal for November 23, 1901. In view of the fact that the sample train sheets used by Mr. Wynne follow the same practice as that in the article referred to, viz: plotting distance horizontally, and time vertically, and recollecting an adverse criticism by a steam railway engineer because such plotting is the opposite of that used for train records, it seems probable that a few remarks on this subject might be of interest.

Train sheets are prepared and used by two departments, viz: the engineering and the operating departments, and although the train sheets prepared by the latter are, to a greater or less degree, based upon the work of the former and assist in the preparation of the time tables, train sheets, etc., as finally decided by the latter, nevertheless, the actual use of the train sheets is so different, both as to the person using them, and as to the purposes for which they are used, that it seems to the writer that they should be considered as entirely different, and that each should be prepared in such manner as to be most useful for the purpose for which it is prepared and without reference to the other.

The engineer prepares a train sheet for at least three purposes:—

First—To give him a mental picture relative to the location of trains with respect to each other, and with reference to grades, curves, and other factors affecting speed, power, etc., which picture assists him in the preparation of the design. In this connection, it might be noted that the electric railway engineer has more need of such a bird's-eye view, or can use it to greater advantage, than the steam railway engineer, for the reason that, in the case of an electric railway, each train is not a self contained power unit, and therefore the electric railway engineer has to consider the inter-relation between the location of the trains and the provision for the distribution of the power from the power house to the train, including both the line and the location and capacity of the sub-stations.

Second—The engineer uses the train sheet as a graphical record of the design.

Third—The tentative train sheet, with train movement and other data hereinafter mentioned is of great use in connection with reports for financing a proposed road, because it graphically presents a comprehensive bird's-eye view of many important features and their inter-relation.

The operating department prepares a train sheet as a preliminary to the preparation of a time table, or coincident therewith, and the diagram so prepared may either be a drawing, or pins placed in a board with threads (generally of different colors according to class) to show the movement of cars and from which a drawing may finally be prepared recording the train movements decided upon. The possible train movements are largely controlled by the physical design of the road, including in the case of an electrical road, the design of the distributing system. In addition, the operating department makes daily records of all train movements on blanks prepared for such purpose, but such train sheets are of quite different character from a train diagram and are train records, or sometimes termed train registers. They consist of a sheet having horizontal and vertical lines, the stations are noted in a vertical column placed in the center and twenty-four vertical columns are provided on each side: one side is used for trains in one direction, the other for trains in the opposite direction, and the time is noted in the vertical column; the result is that the train movements are recorded in a diagonal direction. The record, however, is not graphical.

An operator is accustomed to consider the relative position of stations the same as a time table, namely, vertically, whereas engineers are accustomed to considering distances horizontally, and

that the distances are fixed, and that the time made by the train between the stations is the variable, and as the engineer is used to plotting the variable on the vertical, or as an ordinate, it is natural for him to so prepare a train sheet.

The operator considers hours as being the constant, and the distance which the train may run, (or in some cases, the length of the division) as the variable. Moreover, the earlier train sheets and records were made on boards having a fixed width and variable length, and the width was the controlling dimension for hanging on the wall and for filing and was divided into twenty-four hours, and the length varied with the length of the division.

The train sheet prepared by the electric railway engineer gives a graphical record of the train movements, in the manner described and in addition many, or all, of the following records are shown just above the record of train movements:

First—A condensed profile.

Second—The alignment, with curves designated by arcs of circles with degree of curvature marked thereon.

Third—The location of passing tracks, (with their clear length), spurs, bridges, grade crossings, town limits, limits of private and public rights-of-way, and similar features.

Fourth—The location of the power house and sub-stations, rated capacity of units therein, and diagram of distributing system, including transmission from power house to sub-stations, and from sub-stations to cars.

If there is any difference in the weight or type of the rails, it can be noted, as well as the carrying capacity and clearance of the bridges, their age and when repaired, and the age of the rails, and similar features.

The writer believes that a train sheet as prepared by and for the engineering department is most readily apprehended by one who is not informed respecting the subject, and this is of value in connection with the presentation of a project to financial parties. It can be readily appreciated that if even a considerable portion of the above-stated data is noted, that it is far more convenient to read the record if it is in such position as to give distance horizontally.

Some steam railways have their engineers prepare sheets for the operating department with all, or a considerable portion, of the above-stated information marked thereon, but without showing the movement of the trains, and with grades designated as feet per mile. Then with the assistance of such graphical and comprehen-

sive record, the operating department prepares its train sheet. Such being the case, it may be noted that steam railways even now have a different basis for the engineering and operating departments, and therefore, even though it is a fact that the operation of electric railways relative to dispatching trains is following, more and more nearly, steam railway practice, and that electric railways obtain men from steam railways for such purpose, nevertheless the writer does not consider that any injurious results will, or may, follow the use by engineers of a method different from that used in the operating department, and consequently that the adverse criticism is not justifiable, and that standardizing is not advisable.

If, however, standardizing is advisable, it seems to me that it would be wise to follow the basis used by the operating department for the following reasons:—

First—The number of men using such train sheets or records is greatly in excess of those using train diagrams, as prepared by the engineers.

Second—That dispatchers, at least generally speaking, can not readily and surely change mental conceptions.

Third—That a mistake made by dispatchers may result in accidents, as frequently there is not time for a dispatcher to rectify an error even if it is discovered shortly after having been made, whereas such will not be the case with errors in train diagrams made by and for the enginering department.

E. P. Roberts

Single-Phase Railways

The article entitled "Some Notes on the Single-Phase Railway System," by Mr. Renshaw, in this issue of the Journal, deals with one of the most interesting phases of railway operation in a peculiarly interesting manner. A number of the early papers dealing with single-phase railway operation bristled with mathematical formulæ and peculiar diagrams of confusing connections. Many later articles deal with the constructive, operating or commercial features of the subject in a scientific and profound manner. Mr. Renshaw gives an informal talk rather than a formal dissertation. He treats all interesting and novel features of single-phase operation in a way which will appeal to all classes of readers and will doubtless be of much assistance in making clear numerous points which have been puzzling and confusing to many. The merit of his article consists not only in its subject matter, on which he is an authority, but also in its happy method of treatment.

SOME NOTES ON THE SINGLE-PHASE RAILWAY SYSTEM

CLARENCE RENSHAW

ONE of the prominent journals devoted to the interests of electric railways says in a recent editorial, "Single-phase installations are becoming so numerous that they attract little attention, unless accompanied by novel features," and this is indeed true. Even the appearance of the cars with pantagraph trolley on top has ceased to attract the attention of the public. Last July, when the Chicago, Lake Shore & South Bend Railway was opened for traffic, I was standing by the side of one of the first cars in South Bend, looking at the apparatus underneath it, when a by-stander remarked, as if to rebuke my curiosity, "I don't see that these cars are any different from any others." "Why should they be?" I asked. "Oh, I don't know," he answered, "but I had sort of understood that they were going to be different in some way." Thus the single-phase railway has ceased to be a curiosity, a novelty, or an experiment, and has taken its place among ordinary work-a-day things. This does not mean that the matter has lost interest as a subject for discussion among engineers—far from it—or that the importance of the single-phase system to the general art of electric railroading has in any way been lost sight of.

One of the characters in "Gulliver's Travels" gives it as his opinion "that whoever could make two ears of corn, or two blades of grass grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together," and the making of two blades of grass grow where only one grew before, has become the ideal of productive activity. It seems to me that in making it commercially possible to operate electric railways through districts where it would be impossible on any other basis, the single-phase railway system performs a service for the public fully equal in importance to doubling the yield of corn or grass, and fully reaching the above ideal.

In considering how and why the single-phase system accomplishes what it does, the prime factor is that it enables *alternating* current (which can be readily transformed from one voltage to another without moving machinery and with but little loss) and

single-phase current (which can be transmitted over a single pair of conductors, i. e., one wire and the track or ground) to be used throughout from generators to motors. Two other essential points are, first, that motors and control apparatus having the same fundamental characteristics as those of their direct-current proto-types, can be manufactured to utilize this current, and can be made sufficiently simple, reliable, efficient, light and cheap to warrant their use, and second, that a method of trolley line construction has been devised by means of which the high voltage trolley wires, which are necessary to the success of the system, can be safely and securely supported. The results which follow from the use of this system are simply astounding when one starts to consider them for the first time.

The principal difficulty in planning direct-current interurban railways is to provide for a reasonably uniform supply of power at

MARKETING WHEAT VIA SPOKANE AND INLAND SINGLE-PHASE RAILWAY

the cars without an unreasonably great expenditure for rotary converter sub-stations and feeders. This is due to the fact that in a direct-current system, the power must be transmitted at essentially the same voltage at which it is used. The voltage of the direct-current railway motor is limited to a comparatively low value, and hence heavy currents are necessary to transmit large amounts of power.

With the single-phase system, on the other hand, the use of a transformer on each car renders the trolley voltage entirely independent of the motor voltage. Motors operating at 225 or 250 volts can be used in connection with a trolley carrying 6 600, 11 000 or any other desired voltage. By using a high trolley voltage, the amount of current which need be transmitted for any given power, can be reduced to a very small value, while at the same time the

use of the transformer gives a safe low voltage on the motors and control circuits.

In order to obtain a more definite idea as to just what this means, let us consider some concrete figures. The drop in voltage and the loss of energy in transmission depends upon the *current* transmitted, and not upon the power. The same feeder, therefore, which gives a drop of 120 volts, or 20 percent, in transmitting 150 kilowatts, at 600 volts (i. e., 250 amperes) for any given distance, will have only the same voltage drop (i. e., 120) if transmitting 1 500 kilowatts at 6 000 volts (i. e., 250 amperes as before) the same distance. Furthermore, in the latter case, the percentage drop will be only two percent instead of 20 percent. To transmit 150 kilowatts at 6 000 volts for any given distance with a given drop in voltage, therefore, will require a cable only one percent as large in cross-section as that required for transmitting the same power at 600 volts.

CARS ON THE HANOVER AND YORK STREET RAILWAY

Before the above figures can be applied to actual conditions, two other factors must be considered. In a circuit composed of trolley wire with rail return, the drop in voltage with direct current depends merely on the ohmic resistance, and the product of the current flowing by the volts drop gives the value of the energy lost. In the case of alternating current, however, there is in addition a certain inductive drop. The track rails also offer a greater resistance to alternating current than they do to direct current. On this account, the drop in voltage in such a circuit is somewhat greater with a given number of amperes alternating current, than it is with the same amperes direct current. The drop in voltage with alter-

nating current, however, does not all represent loss of energy, but usually the product of the alternating current flowing in such a circuit, by the drop in voltage gives a result about 40 percent greater than the value of the energy lost.

For a circuit composed of a No. 3/0 trolley wire, with catenary construction and two 70 pound track rails, the actual drop with 25 cycle alternating current is approximately 60 volts per 100 amperes per mile while that for direct current is approximately 36 volts per 100 amperes per mile. The power-factor of the alternating current in this circuit is approximately 60 percent. That is, in any given case, the loss of energy is equal to approximately 60 percent of the

FOUR CAR SINGLE-PHASE TRAIN
Rochester Division, Erie Railroad.

product of the current flowing and the volts drop. With the aid of the above figures, we can now get at the vital point of the single-phase system. An ordinary direct-current interurban car equipped with four 75 horse-power or four 90 horse-power motors, and weighing from 37 to 40 tons with average load, requires as a rule from 200 to 250 amperes when running at full speed of about 50 or 55 miles per hour on the level, and from 400 to 500 amperes when starting. Grades of even one or two percent may considerably increase these figures.

Assuming a level track and fixing the minimum allowable voltage at the car as 250, such a car could be fed from a 600 volt substation by means of No. 3/0 trolley wire for a distance of only

about two and one-half miles, or from a No. 3/0 trolley wire and a 500 000 circ. mil feeder for approximately seven and one-half miles. In either case, the maximum drop in voltage would be nearly 60 percent and the average drop in voltage and loss of power from about 20 to 25 percent.

The same car, if equipped with 6 600 volt single-phase apparatus, capable of carrying the same load at the same speeds, would require a current not exceeding 30 amperes, when running at full speed, or 50 amperes when starting. Such a car, with a No. 3/0

CAR EQUIPPED WITH FOUR 100-HORSE-POWER SINGLE-PHASE MOTORS FOR OPERATION ON BOTH SINGLE-PHASE AND DIRECT CURRENT

Pittsburgh & Butler Street Railway.

trolley wire only, could be supplied with power for a distance of nearly 45 miles, and even then the maximum drop in voltage would approximate only 20 percent and the average loss of power only about six percent.

These figures are not the result of a facile pen and a slide rule, that does not locate the decimal points, but can be substantiated by referring to conditions actually existing on numerous roads. One of the best and most carefully planned direct-current interurban

roads in the world, is the Indianapolis-Logansport Line of the Indiana Union Traction Company, and by far the greater part of this line is straight and level. The cars are equipped with four 75 hp motors, and weigh about the same and require about the same currents as the typical direct-current car just referred to. The line is approximately 80 miles long, and is fed by five sub-stations from 17 to 19 miles apart. The trolley wire is No. 3/0 and in addition to it there is a 600 000 circ. mil feeder between the two sub-stations nearest Logansport, and a 550 000 circ. mil feeder the remainder of the distance. The ordinary schedule calls for a total of eight cars on the entire line, which are operated as single units. This property

6 600 VOLT LINE CONSTRUCTION USED IN CITIES AND TOWNS
Pittsburgh & Butler Street Railway.

is a typical example of the very best direct-current practice at the time it was installed. If this line were operated at 6 600 volts, single-phase, the trolley wire only would have ample capacity for supplying power to the cars, and 19 miles of 600 000 circ. mil and 58.5 miles of 550 000 circ. mil cable, weighing over 800 000 lbs. and costing in the neighborhood of $130 000 would be unnecessary.

Each of the five sub-stations consists of a good sized building, containing two 250 kw rotary converters, together with the necessary transformers and switchboard panels as well as a storage battery and booster outfit. There are thus ten 250 kw rotary converters, fifteen 375 kw transformers, 35 switchboard panels and five

storage battery and booster outfits, used for the operating of eight 37 ton cars. If it were not for the difficulty of transmitting power and if the cars could be fed from a single sub-station, less than one-half of the combined capacity of the above apparatus would be sufficient.

If this line were operated by the single-phase system at 6 600 volts, it could be fed for the entire distance from two transformer stations, each containing two 500 kw, single-phase transformers, and the entire outfit of rotary converters, transformers, and batteries mentioned above could be done away with. The transformers could be housed in much smaller buildings than the rotary converters and batteries, and much less switching apparatus would be required for handling them. In other words, instead of five sub-stations, with ten rotary converters, fifteen transformers and five storage batteries with auxiliaries, there would be two sub-stations of a smaller size with a total of four transformers. What is perhaps of more importance, however, is the fact that of the ten men necessary to care for the five rotary converter sub-stations, nine could be released entirely, and a portion of the time of the tenth man devoted to other work than caring for the transformer stations, as these do not require constant attendance, but merely an occasional inspection.

The Chicago, Lake Shore & South Bend Railway, a typical single-phase line of about the same general character as the above, operates approximately 75 miles of line from South Bend, Ind., to Kensington, Ill. This line has 23 interurban cars, much larger than those of the Indiana Union Traction Company, which are equipped with four 125 hp motors, and weigh approximately 56 tons with average load. The line is laid out to permit the operation of these cars in trains of two or three cars each, and yet all the power is transmitted by a No. 4/0 trolley wire. This is fed from the power station near the middle of the line, and from two transformer stations.

At first only that portion of the line between South Bend and Michigan City, a distance of 34 miles, was put in operation. When this was first opened, the sub-station near South Bend was not yet ready for service, and so for a considerable time the 56 ton cars were operated over this 34 mile section, at times, at one-hour headway with the No. 4/0 trolley fed from the power station only.

In the case of the above direct-current road, we were dealing with a large system and one of the best of its kind. These advant-

ages may be brought out even more strongly by citing the case of a small interurban road in Ohio which came to my attention about two years ago. This company controlled two lines, one from A via B (5½ miles from A), Fig. 1, to *C*, 18.75 miles long, and the other from A via B to D, about the same total distance. Three cars were operated, two between *A* & *C* and one between *A* & *D*. These cars each weighed approximately 30 tons, and were equipped with four 60 hp motors. The power was supplied from three sub-stations as shown in Fig. 1. Each contained one 300 kw rotary converter, and three 150 kw transformers, together with the necessary switch-board panels. Power was purchased from another railway company at *X*, 50 miles from A, and transmitted over three aluminum wires, each equivalent to approximately 57 300 circular mils of copper.

The line from *A* to *C* had two No. 4/0 trolley wires and in addition to these, aluminum feeders equivalent to approximately 6 500 lbs. of copper. The line from *B* to *D* had a No. 4/0 trolley wire only.

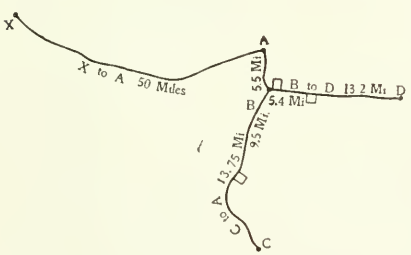


Fig. 1

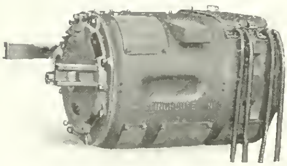
In this case, three rotary converter sub-stations were maintained in order to operate the same number of cars, all of which could have been supplied with power from any one of the three sub-stations, if the latter could have been kept within feeding distance of the cars.

In January, 1906, a total of 116 500 kw-hrs. was used from the power station, of which approximately 52 700 or 45 percent was required merely to keep power on the line. This left 63 850 kw hours (or 3.07 kw-hrs. for each of the 20 577 car-miles made during this month) for running the cars.

Had this line been operated by the single-phase system, it could have been supplied from a single 500 kw transformer located at almost any point along either line, and there could then have been released from this property,—

2—substation buildings,
3—300 kw rotary converters,
9—150 kw transformers;
3—switchboards.
116 500 equivalent pounds of copper trolley feeder and high tension wire.

Even then a further saving could have been effected by using a No. 3/0 trolley instead of No. 4/0. In addition to this, the services of six sub-station attendants could have been dispensed with. This seems ridiculous, but it is absolutely true, and it is only for obvious reasons that I am refraining from giving the actual names of the towns.



ONE HUNDRED HORSE-POWER SINGLE-PHASE RAILWAY MOTOR

These instances, which may be regarded as typical, should be sufficient to show the large economies which may be effected by the use of the single-phase system, and to indicate why it is that single-phase railways can be profitably operated where direct-current ones cannot. They should also indicate why the consulting engineers (a Chicago firm of national reputation) of a large single-phase line in the middle west, in making their final report in connection with the acceptance of the apparatus by the Railway Company, estimated after an exhaustive investigation that an annual saving of $16 000 per year was being effected over the cost of operating the line by means of the direct-current system.

6 600 VOLT TROLLEY LINE CONSTRUCTION
Pittsburgh & Butler Street Railway.

After considering these facts, one does not wonder that although it is not yet four years since the first commercial single-phase railway line, (that of the Indianapolis & Cincinnati Traction Company) was opened for traffic at Rushville, Indiana, approximately 1 000 miles of line are now operated in the United States and Canada by 25 railway

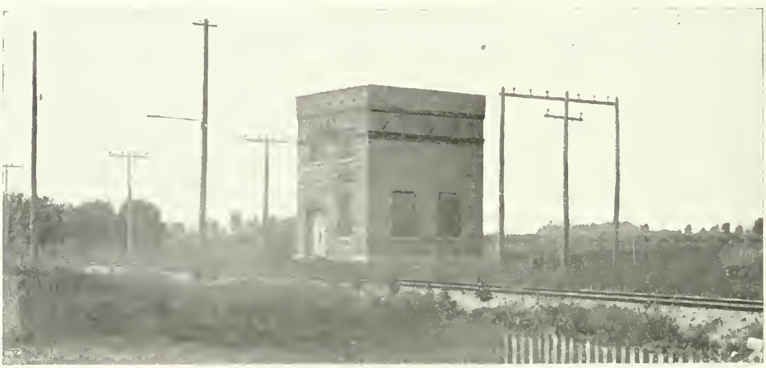
companies, employing 1 275 motors totalling approximately 134 500 nominal horse-power. These figures alone are of considerable interest from an engineering standpoint, but there are facts in regard to almost everyone of these railways which are of even greater interest from a broader standpoint.

Four of the lines represented consist of electrified branch lines formerly operated by steam locomotives. On one of these lines the use of electricity as a motive power has enabled the railway company to operate seven clean and attractive trains each way per day, instead of three antiquated and dilapidated ones formerly hauled by steam locomotives. The benefit of the change to the railway company is shown by the fact that within three months after starting the electric service, the average passenger receipts from all of the stations along the 34 miles of line had increased approximately 100 percent, while those of several individual stations increased considerably more even than this. The benefit of the change to the community can hardly be expressed in any of the ordinary units. I had occasion to travel over a portion of the line several times just before the electric service was instituted, and once just afterwards. Entirely aside from the increased frequency of trains, I found the relief from the smoke, cinders and dust so great, that I sympathized heartily with the old lady from one of the country stations, who rode up to the city and back on the first day of the electric service, and was so pleased with the change that on leaving the car she personally thanked the conductor and motorman for her pleasant ride.

This case is typical of the results obtained from the electrification of steam railroad branches. The conditions just described were almost exactly duplicated on a second one of the four electrified lines referred to, which increased the number of trains from seven to eighteen. Such electrifications are, of course, entirely practicable from an engineering standpoint with direct current apparatus. The 34 mile line just referred to, however, on such a basis, would have required at least two and probably three sub-stations and a considerable amount of copper feeders. Each sub-station would have required two men, one for the day and one for the night shift, and finally when this system had been put in and was working at its best, the company would perhaps have been able to run trains consisting of one motor car and one trailer or perhaps two motor cars. Under these conditions, unless a third rail had been installed instead of an over-head trolley wire, the voltage at times would probably

have been as low as 250 or 300, giving poor illumination and slow speed.

With the single-phase system, as installed, using a No. 4/0 trolley wire only, fed from a single transformer station near the middle of the line, several four-car trains, consisting of two motor cars and two trailers, are run every day and at times three motor cars have been coupled together and operated as one. Even under these conditions, a steady illumination is obtained, so that a newspaper may be read in the cars at night at any point along the line. Think of attempting to lay out a direct-current system 34 miles long, to operate six 48-ton cars, each equipped with four 100 horsepower motors, so that three of these cars could be operated in a single train, with a drop in voltage not exceeding 20 or 25 percent.



SINGLE-PHASE TRANSFORMER STATION
Indianapolis & Cincinnati Traction Company.

Many of the interurban lines are equally interesting. The York Railways Company have a number of direct-current suburban lines radiating to various small towns, 10 or 12 miles distant. Most of these lines are fed from a sub-station at York with the aid of boosters. The cars are for the most part equipped with four 40 horse-power motors and run once every hour. Even under these conditions a voltage variation of from about 250 to 750 is obtained on the lines, and it is sometimes difficult for the cars to climb the grades. The same company last February opened a 6600 volt single-phase line from York to Hanover, a distance of 19 miles. The single-phase cars weigh approximately 45 tons each with average load, and are equipped with four 75 horse-power motors geared

for a speed of about 40 miles per hour. This line is fed from the same point as the direct-current lines, and consists merely of a single No. 4/0 trolley wire with absolutely no feeders. When the line was first opened, motormen from the other suburban lines were assigned to the new cars and it was a never-ending source of wonder and delight to them that the big cars climbed a seven percent grade at the distant end of the line with apparently no effect on the power, and their wonder indeed was well founded, for careful voltage measurements showed that the maximum drop in voltage at the motors rarely exceeded five percent.

Although Hanover can be reached from York by two different steam railroad lines, the service on each is slow and tedious, and the stations are located in out-of-the-way parts of each town. The electric cars, making the run of 19 miles in 55 minutes, (which is less time than that required by the steam roads) runnnig every hour in each direction, and carrying their passengers directly to the business center of each place, have proven a remarkable convenience to the public. While riding over the line a short time ago one of the motormen, whom I had known when the line first opened, expressed the result of the operation of this line very tritely by remarking that Hanover did not seem nearly as far off as it used to.

Almost everyone of the single-phase roads now in operation has some interesting circumstance in connection with it. The Indianapolis and Cincinnati line, for instance, operates what is probably the fastest interurban electric service in the world. Their "flyer," the "Connersville Despatch," makes the run between Indianapolis and Connersville, a distance of 58 miles, in one hour and thirty minutes, thus making an average speed of nearly 39 miles per hour. Moreover, about thirty minutes of this time is consumed in covering six miles of slow speed running in Indianapolis, Rushville and Connersville, so that in the open country these cars make the remarkably rapid run of 52 miles in one hour. On account of this high speed schedule the cars which make these runs have frequently covered as much as 586 miles in a single day and in several instances cars have made nearly 10 000 miles per month for three consecutive months. During the same three months in which the above individual records were made, the entire number of cars in service averaged approximately 6 500 miles per month. So far as I know, these figures, both for speed and mileage, are considerably better than those for any other interurban road in the world, whether operated by direct-cur-

rent or single-phase motors and they bear witness in a remarkable degree to the reliability of single-phase apparatus.

Another interesting single-phase line is that of the Pittsburgh & Butler Street Railway Company, from Pittsburgh to Butler, Pa., a distance of 40 miles. This line is remarkable for the rugged character of the country through which it passes. Among a number of grades of 5 and 6 percent there is one of approximately 9.5 percent near the extreme end of the line and four miles beyond the last transformer station. Fed only by a No. 3/0 trolley wire, the 40-ton cars used on this road not only climb this grade regularly in service, but are able to haul a second car as a trailer up it and around a 50 foot curve at the top, in an emergency. Due to the use of the single-phase system, the management of this road is enabled to serve the public with larger and more comfortable cars and a much higher speed service under the adverse conditions of grade and curves than it could otherwise afford to do.

TRANSFORMER STATION FOR SINGLE-PHASE LINE.
Warren & Jamestown Street Railway.

The Spokane & Inland Railway, of Spokane, Wash., also has a condition as regards grades which is unique. In this case the grades are notable for their length rather than their steepness. At one place there is a continuous length of two percent grade for a distance of eight miles, and with transformer stations ten miles apart and only a No. 3/0 trolley wire for supplying power, 72 ton, 6600 volt electric freight locomotives haul 300-ton trains up this grade as well as a number of shorter ones. Fancy the problem of handling such a traffic by means of a direct-current trolley wire.

In addition to the important features of the single-phase system, there are a number of incidental advantages and conveniences in connection with it. One of these, especially where power is obtained from a long transmission line, is the ease with which current may be restored to the trolley wire after having been temporarily

interrupted from any cause. The single-phase line of the Erie Railroad from Rochester to Mt. Morris receives power over a long 60 000 volt transmission line from Niagara Falls. During the summer of 1907, when the electric service was first started, a large amount of trouble was being experienced with the transmission line and power would occasionally go off of the 60 000 volt line. With the single-phase system it could be restored to the trolley again within a very few seconds after it was thrown on the transmission line, thus reducing the delay to the cars to a minimum. With a rotary converter or synchronous motor-generator system, considerable time would have been required for starting and synchronizing the rotary converters or motors after power had been restored to the transmission line, before direct-current power could have been again furnished to the cars.

The Spokane & Inland Railway Company have made use of this feature of the single-phase system also to effect a considerable saving in the cost of power. Their line, which is approximately 160 miles long, receives its power in the form of 60 cycle, three-phase current from the Washington Water Power Company at Spokane. The 60 cycle current is there transformed at a frequency changing station into 25 cycle single-phase current for use on the line. As is the case with all water power plants, the peak load is an extremely important item and the power contract is so drawn up that a heavy peak used even for a very short time may have a large influence on the power bill for an entire month. When the switchboard attendant at the frequency changing station sees a peak coming, therefore, he cuts off current from the line for a few moments, as a matter of warning to the motormen who have been causing the heavy pull and then switches it on again. Imagine trying to control the current supply to a 160 mile direct-current line in any such fashion.

It is unnecessary to dwell at length on the catenary line construction used with the single-phase system or on the details of the car equipment, since in the large problem of choosing between the direct-current and single-phase system these matters are mere incidents and it is usually sufficient to know that satisfactory line material and suitable car equipment can be obtained. A few words in regard to them, however, will not be out of place. In the line construction ordinarily used for interurban roads or steam railroad branches, wooden poles with iron bracket arms are employed. These are usually placed 120 feet apart on straight track. Where

rigid economy is necessary, however, a spacing of 150 feet can be used. Ordinary transmission line porcelain insulators suitable for the voltage and with convenient clamps cemented to them, are secured to the bracket arms and to these insulators, a 7/16 inch stranded steel cable, called the "messenger" cable, is secured. In putting this cable in place it is pulled up to a definite tension between each two poles, the exact value of which is varied according to the distance. At any given atmospheric temperature there is a fixed relation between the "sag," or deflection from the horizontal, of the cable at its middle point and the tension, and in erecting such a line the "sag" is employed as a convenient indication of the tension. The trolley wire is run below the bracket arms and is secured to the messenger cable at intervals of ten feet by suitable hangers. Hangers of different lengths are used at different parts of the span so proportioned that the trolley wire is maintained almost exactly parallel to the track.

At suitable intervals on straight track, and at every pole on the curves, a "steady strain," consisting of a large hard wood stick secured to the trolley wire and to the bracket arm, is used to maintain the line in its proper position. On curves the poles are placed closer together than on straight track and the spacing is so adjusted for curves of any given radius that the trolley wire is maintained within a reasonable distance of the center of the track. This construction has proven remarkably strong, secure and satisfactory. It is practically impossible for such a line to become sufficiently damaged to permit the wire to fall to the ground, and it would even be a difficult job to pull it down with an ordinary block and tackle.

In regard to the car equipments, the single-phase motor, which is, of course, the essential factor, consists merely of a direct-current motor of such excellent design and construction that it will operate on alternating current. It has been known for years that a direct-current series motor would run on alternating current, but in order to make such operation commercially satisfactory, many refinements such as the use of a completely laminated magnetic structure, and auxiliary or compensating winding, resistance leads, etc., are necessary, and it is only during the last few years that, by the addition of these items, the single-phase motor has been perfected.

The control of single-phase motors is a much simpler problem than that of direct-current motors, since with a transformer on each car in any case, it is an easy matter to bring out a number of

different voltage taps and connect the motors to any one of them, according to the speed desired. Series parallel connections, with their attendant complications, which are necessary with direct-current motors, in order to obtain economical operation and a second running speed, may therefore be entirely done away with and the motors connected permanently in any desired grouping. In order to simplify the wiring and connections, the grouping ordinarily used for a four motor single-phase equipment is two motors in series and two in parallel.

In order to avoid the necessity of opening the circuit in passing from one transformer tap to another, the motors are connected to the transformer through preventive coils. In the case of large equipments, pneumatically-operated switches controlled by magnet valves are used for making the various connections, the same as for direct-current unit switch control. For small equipments, hand controllers, similar in appearance to those used with the direct-current equipments, may be used.

An important feature of single-phase equipments is the pantagraph trolley. This consists of a flat shoe supported on a frame work which is raised and held against the trolley wire by springs and is lowered by compressed air. It is completely under the control of the motorman, who can raise or lower the trolleys of an entire train simultaneously without leaving his cab.

The single-phase motor may be operated on direct current and where it is desired to obtain the benefits of the single-phase system in the country, while at the same time it is necessary for the cars to enter one or more cities or towns over the tracks of existing direct-current roads, single-phase equipments can readily be arranged to meet the conditions. In such cases a slow speed is usually desired on the direct-current portion of the line and a higher speed on the single-phase portion. This is accomplished by connecting the motors four in series on direct current and two in series and two in parallel on alternating current. In this way, with 600 volts direct current, a speed about two-thirds or three-fourths of that with normal voltage, alternating current, is secured.

The figures given in the earlier part of the article, on the rapid increase in the use of single-phase apparatus during the few years that it has been available, are in general strong evidence of the favor with which it has been received. There have been a few critics. One of the principal contentions of these has been that the weight of cars equipped with single-phase motors is enormously greater

than that of similar cars equipped with direct-current motors. In order to present the matter of weights as it actually exists, I am giving some comparative figures regarding the weight of certain definite equipments with which I am familiar.

One of the most popular single-phase equipments for use both on alternating current only and on roads where direct-current operation is also necessary, is a quadruple equipment of 100 horse-power motors. I have no data available on a direct-current motor of exactly this size but have on a 90 horse-power one, and quadruple equipments of these motors are also very popular for use on direct-current cars. I am, therefore, using this 90 horse-power direct-current motor for comparison with the 100 horse-power single-phase motor. The weight of the 90 horse-power direct-current motor only, complete with gears and gear case, is 4 300 lbs. That of the 100 horse-power single-phase motor is 5 300 lbs. A quadruple equipment of these 90 horse-power direct-current motors with train control weighs 20 100 lbs. A quadruple equipment of the 100 horse-power single-phase motors with train control for operation on alternating current only, weighs 31 500 lbs. or 34 500 lbs. if arranged for operation on both alternating and direct current.

In operation, however, it is not the weight of the equipment alone which must be considered, but the weight of the complete cars, together with their passenger loads. The car on which these equipments would ordinarily be mounted, would weigh approximately 65 000 lbs. complete with air brakes, to which the ordinary passenger load would add about 5 000 lbs. more. Such a car, if equipped with quadruple 90 horse-power, direct-current motors, would weigh 90 100 lbs. The same car, if equipped with quadruple 100 horse-power single-phase motors would weigh 101 500 lbs. for operation on alternating current only, and 104 500 lbs. for operation on both alternating and direct current. The total weight, therefore, of the car complete with average load, when equipped with 100 horse-power single-phase motors, would be only 12 percent more in the first case, or 15.5 percent more in the second case, than it would if equipped with 90 horse-power direct-current motors, in spite of the fact that the single-phase motors would have 11 percent greater capacity than the direct-current ones.

SOME OPPORTUNITIES ON THE SHOP SIDE IN THE ENGINEERING INDUSTRIES

C. B. AUEL

CIVILIZATION has reached such a stage as to make necessities to-day of yesterday's luxuries, or if this be considered too radical a statement it may be modified by saying, that there are now required for our comfort and well-being, many things which our forefathers, in their simpler modes of life, could not and would not have made use of. Whether theirs was in consequence the better life, is however, as Kipling would say, "Another story." This advanced degree of civilization is constantly bringing into life new industries and enlarging old ones. As evidence of this, one has but to look about almost anywhere and note the various manufacturing establishments and the small number that have been in existence more than a quarter of a century. Taking at random almost any of them, it will be seen how comprehensive in scope it has grown, and although possible a few years ago for an individual to master the entire details of the business, how utterly impossible to do so now. The seemingly huge works has become to all intents and purposes a number of smaller factories, each making one or more specialties or parts and being largely independent of one another, though banded together and housed under the same or adjacent roofs for mutually advantageous ends which otherwise could not be so readily attained. A further sub-division of work and of responsibility has also been made imperative in practically every concern due to the constantly increasing severity of the requirements to be met by its products. As a result of this departmentalizing and of the sub-dividing of responsibility, there is a certain paralleling of forces, commencing with the management and extending down through the entire organization. Since the ultimate end of capital is dividends, this paralleling of forces would seem at first glance to run counter to real economy. This is not so, however, as an intimate knowledge of conditions will clearly show.

In consequence of the preceding, it is necessary for every manufacturing concern to secure either by development or otherwise, specialists along various lines, men who by concentrating their attention on some one subject or even on a part of one subject, become experts on it and who accordingly act in a managerial or

advisory capacity in such matters, producing maximum result at minimum cost in minimum time. To one who has not had occasion to study manufacturing conditions as they are to-day, it seems almost beyond belief, when their attention is drawn to the subject for the first time, that there can be any need for so many distinct lines of specialization. The case is, however, somewhat like that of the human organization. Where formerly a medical practitioner was supposed to know all about every portion of the body, it is now recognized that this is in excess of the capabilities of a single individual, and we have, therefore, specialists on every important part—eyes, ears, nose, throat, lungs, bones, nerves and so on. Looked at from a similar standpoint, the need for specialization in factory organization seems more plausible, in fact quite rational.

There are two ways in which this expert knowledge may be obtained: indirectly, that is, through the experience of others as recorded in books, lectures, illustrations, etc., and directly through personal experience. The first tends to wide though superficial rather than deep learning, while the second confines within narrow channels, besides being too long. A combination of the two, however, leaves but little to be desired, especially if both be undertaken at the same time instead of in sequence. It may be said without fear of contradiction that regardless of occupation, education is the soundest investment one can make, for it pays an ever-increasing interest and the greater the investment, the less liable is it to be affected by hard times such as this country has recently been experiencing. While, therefore, it is advisable for every one to invest along this line, to every young man who contemplates following engineering, such an investment becomes an absolute necessity.

For the young college man there is no better way to obtain an insight into the practical side than by taking a full apprentice course with one of the many manufacturing concerns now offering them; and, if such an apprenticeship be entered upon during the college vacations, it will enable the benefits of a college course to be appreciated more fully and to be taken advantage of more largely in consequence.

For the young man who may have had some of the practical side, but who has not had a college course, the technical night schools and the correspondence courses of instruction will be found of very great assistance.

To both the technical and the non-technical young men it seems

necessary to issue a caution not to be misled into thinking that either their technical or their practical training will ever be completed, for neither will be if they are of the progressive kind.

In addition to the qualifications in the matter of training, there are two other equally important essentials which should not be lost sight of and without which a young man will be handicapped even with the best of training; these are hustling and perseverance. A well-known American literateur has said that the number of real literary critics could be counted on less than the thumbs on one's hands. While the situation is not quite so deplorable with respect to real hustlers, the fact remains that they are an altogether rare species and accordingly the one more sought after than any other, unless, perhaps, it be that of geniuses. Hustling is an invaluable asset for anyone to have and while like other gifts it may be natural to some people, it can certainly be acquired by others. The term though inelegant, is so well understood that there is no need to define it, further than to say it does not mean bustling, which is usually the direct opposite. Perseverance, the other essential just referred to, may also be acquired. It is easy for the majority of people to work hard at a task as long as the novelty lasts; but when the novelty has worn away and it has become a matter of routine, then is the time to observe whether or not a young man has the quality of perseverance.

The well-nigh universal desire on the part of apprentices to have done with the shops as quickly as possible and to obtain positions in the offices, has always been a source of wonder to those in authority on the manufacturing side. Such desire can only be accounted for on the supposition that the real conditions are not thoroughly understood; and, in support of this theory, it may be said that there is hardly an ambitious man in the offices but feels he would be the stronger had he spent a longer time in the shops. Barring naught except longer hours, there are positions in the shops as attractive as in any other departments and in making this statement, the correspondence, sales, engineering, accounting and construction departments are taken into consideration. There is, too, this additional feature to be borne in mind, that while a man continues in the shops it is almost impossible for him to be overlooked, since there is practically always a demand from the other departments of a large works for good, experienced men from the shops.

To enumerate some, though by no means all of these positions, without necessarily setting them down in the order of their importance, there are inspectors, time clerks, rate or limit setters, stock-

men, shippers, storekeepers, production clerks, assistant foremen, foremen, assistant general foremen, general foremen, assistant superintendents, superintendents, draftsmen, tool designers, assistant managers and managers. Whether the ultimate goal be the managerial, sales, commercial or engineering side of the business, hardly a position has been named with which a man should not be in some degree familiar either through having filled it himself or through having been closely related to it. Not one among them but is important and almost necessary as a stepping stone in his education and advancement.

Take, for example, the position of inspector. A few years ago there were many manufacturing establishments and perhaps a majority of them where such an occupation was unknown, but now this work is considered of the very first importance; so much so, that there are being organized all over the country independent companies who make a specialty of inspecting various items of manufacture for those who choose to employ them. Even a large concern like the Westinghouse Electric & Manufacturing Company, with a force of about 150 trained inspectors of its own, still finds it necessary to enlist outside assistance in this work. Some of these inspection firms adopt a regular label or trade mark with which to stamp all goods inspected by them, and goods so stamped have a higher value among many users on this account. Along somewhat similar lines may be mentioned the various inspection companies insuring property and plant of all description against loss or damage by fire, accident, etc. It will therefore be evident that the work of inspection is assuming wider and more important proportions, not only within manufacturing companies, but outside of them as well. Further, as talent of a high order is required, including a thorough knowledge of the work to be inspected and good judgment in dealing with men, it must be remunerated accordingly.

Take next the position of rate or limit setter. Where formerly workmen were paid almost universally by the day, it is becoming more and more the custom to pay by the piece or else to set a time limit on each job and to pay a premium or bonus if the work is done within this limit. In order to set piece work rates or time limits intelligently, a thorough knowledge of the work and of surrounding conditions down to the smallest detail is necessary. Knowledge of this kind means an intimate understanding of the capabilities of machines and of men as well, qualities similar to those required in an inspector. It is largely for these reasons that

endeavor is made to fill the positions of assistant foremen and foremen from the ranks of rate or limit setters and inspectors, though it should be remembered that while every rate or limit setter and every inspector must be a good workman, it does not always follow that every good workman would make an equally good rate or limit setter or an inspector. Having become assistant foremen or foremen, the positions of general foremen or superintendents are then within reach.

Turning now to the production force, men of somewhat different calibre are required. Here the ability to hustle should go hand in hand with system, accuracy, perseverance and tactfulness, and further, while a general knowledge of tools is essential from the standpoint of their limits of output, it is not at all necessary to know the machines or the work intimately as in the case of rate or limit setters and inspectors. The principal function of the production force is the arranging of schedules for the manufacturing sections so that all orders will be brought through on time, the raw material arriving, being put through the necessary processes and the finished parts being ready for assembling just when wanted, neither sooner nor later. Not everyone appreciates what is generally involved when an order is delayed for any reason after the work has been started in the shop. All labor performed has been paid for and practically all material, yet this investment is idle and not bringing in any returns; whereas, could it have been held in bank, it would have been accruing interest and would also have been available for paying bills on which extra discounts for cash are allowed, or it might have been used in sundry other ways. Again, the raw material and finished parts, if at all bulky, take up considerable floor space which might be used to better advantage than for storage purposes. Finally, the clerical work entailed is by no means a small item. To arrange proper schedules of work and to see that they are adhered to, requires generalship of no mean order and any production clerk who can handle this work as it should be handled is bound to advance himself.

Consider next the time clerk. Here qualities in great measure like those of a production clerk are needed, in fact a good time clerk should be a good production clerk and vice versa and the positions are often interchanged or combined. Upon the time clerk devolves the checking of the workmen's time so that it may be properly posted and thus enable a correct distribution of the pay roll to be effected, both as to the workmen and to orders. Before apparatus is placed on the market, the cost to build it should be known; if too

expensive it can hardly be sold and steps must be taken to lower the costs either by cheapening the method of manufacture or by changing the design; on the other hand, if sold too low through wrong costs being figured out, profits will become deficits and the sole reason for the continuance of any company will disappear. The individual workmen's time records may therefore be considered as the very foundation of good business, and if they are not to be relied upon the entire structure, no matter how well developed in other respects, will be absolutely worthless. From the preceding the importance of securing good men for this work will be apparent.

A few years ago the accounting department of most concerns consisted of a treasurer and a bookkeeper, with some clerical help if the works were of large size. Owing to the keenness of competition, however, which has made it positively necessary to know the costs of manufacturing and of selling, accounting has latterly become of the greatest importance and in all concerns of any considerable size will now be found an auditor, works accountant, chief time clerk and paymaster, each of these having one or more assistants. As a direct result of this growing importance of accounting there has also come into existence a most lucrative profession, that of the chartered public accountant. Such men make a business not only of examining or auditing the books of a company, but of laying out schemes for keeping these books and for those whose preferences lie in this direction there is no better place to begin than as a production or a time clerk.

In addition to the foregoing there are other positions which require the combined knowledge of those already described. Men who are thus equipped have it within their range of possibilities to qualify as shop managers or perhaps executive officers of a company, or they may prefer, as being more attractive, to become consulting experts on shop management. This last mentioned field is of comparatively recent origin. It is a constantly widening one; and is attractive to many, as it offers full opportunity to men of matured experience in the problems of the shop.

Much more could be written on this subject, the positions already outlined might further be added to and all described in greater detail. It is believed, however, that enough has been said to show not only that there are opportunities on the shop side of engineering industries worthy of the ambition of any man; but that even for those whose preferences lie outside of the shop, a shop training is essential and the more thorough this training, the better qualified will they be to fill the positions of their choice.

THE APPLICATION OF LOW PRESSURE STEAM TURBINES TO POWER GENERATION*

J. R. BIBBINS

IT is an interesting reflection bearing upon the truth of an old axiom that the commercial retrenchment of the past year has served at least one good purpose, to direct attention to a deserving but unappreciated factor in modern power generation, the low pressure steam turbine. And curiously enough this type of turbine approaches more closely than most radical engineering developments, to that commercial Utopia, "getting something for nothing." The entire potency of the low pressure turbine, lies in

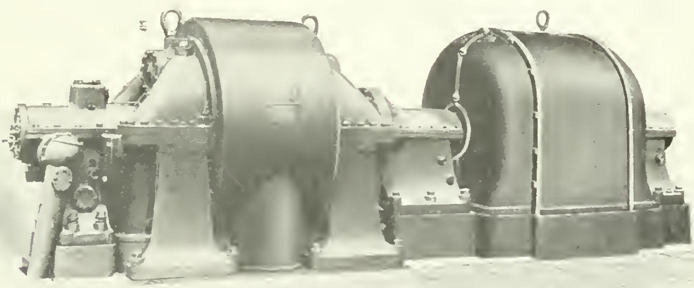


FIG. I—LOW PRESSURE TURBO-GENERATOR SET, WITHOUT GOVERNOR

its ability to utilize a waste product, exhaust steam, or to so improve the general efficiency of a power system as to force a thorough consideration of its possibilities and limitations.

Both of the standard types of prime movers, the reciprocating engine and the steam turbine, have distinct fields in which their highest efficiencies are respectively obtainable. Considering, step by step, the various stages of expansion of steam from the highest boiler pressure to lowest condenser pressures, it is found that the steam engine finds its most efficient territory in the higher ranges above atmosphere, while the steam turbine works to best advantage

*From a paper read before the Canadian Society of Civil Engineers at Montreal, Canada, November 26, 1908.

in the lower stages. This, of course, does not carry the inference that the engine cannot benefit substantially from high vacuum, nor vice versa, the turbine from high boiler pressure, for the advantages of each are well known. But it results from the fact that the reciprocating engine utilizes the energy of steam by static pressure; the turbine by its conversion into dynamic force. In the engine the losses, due to condensation and re-evaporation on the cylinder walls during each consecutive cycle, are large; in the turbine there is no cyclic change, and therefore no such losses, comparatively speaking, as a fairly constant temperature and pressure obtains at any

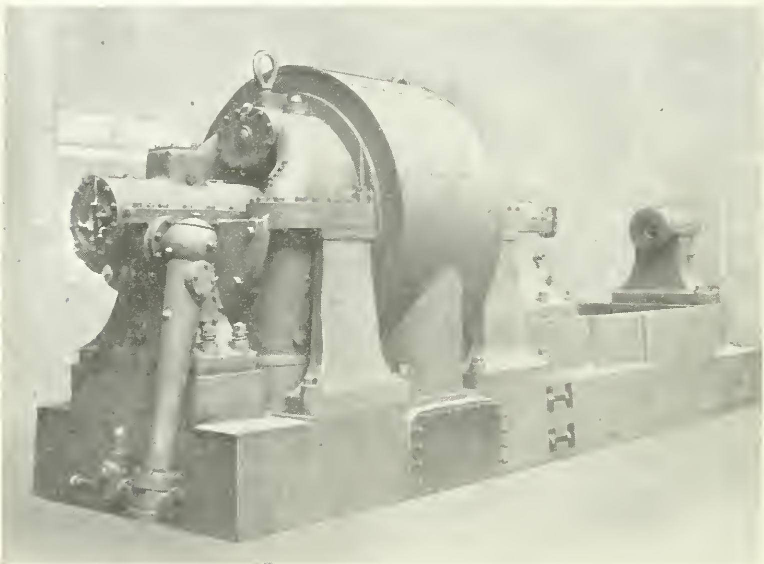


FIG. 2—1 000 KW LOW PRESSURE STEAM TURBINE, WITHOUT GOVERNOR

given point in the expansion range. In the engine, the mechanical friction of the enormous sizes of cylinders necessary to accommodate the lower expansion ranges, constitutes an effective barrier; in the turbine, the lower pressures may be used with comparative ease and without incurring excessive losses, mechanical or thermal. A good Corliss engine, although operating condensing, will give the best efficiency† when operating non-condensing (72 percent at nor-

†It is understood, however, that the term efficiency in his case refers to efficiency ratio in percent of the Rankine-Clausius cycle; i. e., efficiency in percent of available energy in the steam within the range of pressures.

mal load in the case discussed later); that is, against exhaust pressures of from 15 to 20 lbs. absolute. Similarly, the steam turbine, when expanding from 15 to 25 lbs. absolute, will show a maximum efficiency ratio as high as 73 percent for moderate vacuum. And commercial guarantees are to-day made above 70 percent, a fact which speaks for itself. Thus, it occurs that the combination engine-turbine plant will show an over-all efficiency (65 to 75 percent of ideal cycle) considerably in excess of either an engine or complete expansion turbine condensing unit running alone, which can hardly do better than 65 percent. In the case treated later, the Rankine cycle efficiency of the combined unit was found to be 69.3 percent at normal load.

Owing to the excellent papers already presented before the various engineering societies on the general aspects of the subject, it is only necessary to consider here certain phases of the problem pertaining to the use of low pressure turbines in central power stations for lighting, traction and manufacturing. The pioneer work of the Hon. C. A. Parsons (about 1890), to whom we are all indebted, has brought about so thorough a discussion of the marine problem as to take definite form in the decision to equip two monster Trans-Atlantic liners with combined engine and low pressure turbine plant. Prof. Rateau's work in steel mill and mine hoisting, has also resulted in the practical application of low pressure turbines in connection with the steam regenerative principle, permitting the turbines to operate constantly while using the exhaust steam from engines intermittently operated. His work has been brought to our notice in this country by Mr. H. H. Waite in discussing regenerator-turbine application to steel mills†. Mr. J. W. Kirkland‡ has introduced the subject of low pressure turbines in light and power plants. And it is this line of thought that it is desired to enlarge upon in the present paper.

APPLICATION

There are two general classes of service in which the low pressure turbine finds effective field for application:—

Class A—Where the supply of steam is intermittent and widely varying in quantity; for example, (1) rolling mills, for blooms, plate, sheet, wire, rail and structural shapes; (2) steam hammers; (3) hoisting engines. All of these involve the regenerative princi-

†American Institute of Electrical Engineers, December, 1907.
‡National Electric Light Association, June, 1908.

ple, requiring a careful study of the time element in supply and demand, and generally resolving into a special problem for each individual installation.

Class B—Non-intermittent supply without regeneration. This class embraces central power stations for lighting, traction, or for factory drive, and may be discussed as a general problem of power extension where the widely varying plant conditions may be summarized as follows:—

1—Good engine design; fair operating efficiency. Increase in capacity necessary.

2—Inefficient engines, condensing or non-condensing, where

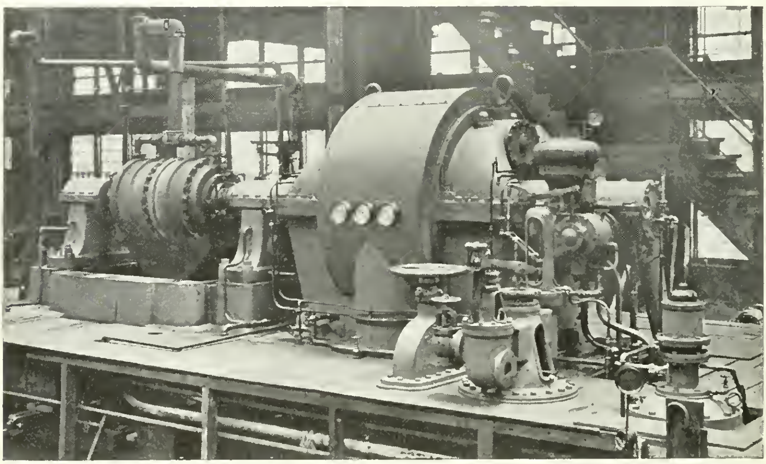


FIG. 3—1 000 KILOWATT LOW PRESSURE TURBINE, WITH GOVERNOR, ON BRAKE TEST

improvements are required to better operating conditions, or enlarge capacity.

3—Unsuitable or inefficient condensing plant.

4—Plant location where water supply is limited, unsuitable or costly; e. g., enforced non-condensing operation.

5—High cost of fuel.

Given a reciprocating engine plant of serviceable construction, along what lines may needed power extensions be made?

1—By installing more reciprocating units of the same type and operating under the same conditions.

2—By installing more efficient complete expansion turbines with suitable auxiliaries.

3—By utilizing the low pressure turbine principle to render the present plant more efficient.

Primarily, the problem considered in this paper is that of *Case B 1* and *2, improving the efficiency of a given reciprocating engine plant* which may be in the best physical shape, but operating under unsuitable conditions. The importance of this subject will at once be appreciated when it is realized that a plant of non-condensing engines may be changed over to reduce its water rate from 30

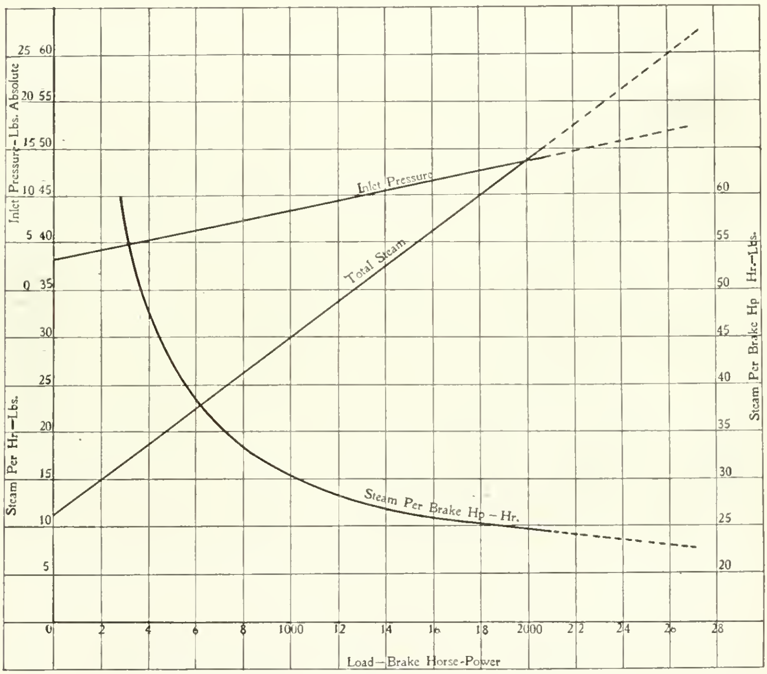


FIG. 4—RESULTS OF ECONOMY TESTS ON 625 KILOWATT (1 000 BRAKE HORSE-POWER) LOW PRESSURE TURBINE

to 35 lbs. per kw-hr. to 15 or 18 lbs. per kw-hr. in comparatively small sizes; in other words, for the same expenditure of coal and water, a net increase in power of from 80 to 100 percent may be realized, depending upon the type of equipment. And the resulting cost of power is reduced in the same proportion. In the case later discussed, a minimum water rate of 15.8 lbs. per kw-hr. (150 lbs. dry saturated steam to 28 inches vacuum) is obtainable from an engine taking 28.5 lbs. per kw-hr. non-condensing, and 20.05 lbs.

per kw-hr. condensing, with an increase in rated capacity of 90 percent; maximum, 100 percent. This water rate is equivalent to 9.9 lbs. per indicated hp-hr., or an efficiency ratio of 75 percent indicated; 68 percent brake.

Turbine Tests—Two series of tests, Figs. 4 and 5 will illustrate the possibilities of economy and capacity. Fig. 4 represents tests at several different loads and varying inlet pressures, all on approximately dry-saturated steam and 27.5 inches vacuum. These tests were all conducted with inlet pressures below atmosphere, but the characteristic for higher pressures is the same, a straight line, as has been proven by other tests carried as high as 30 lbs. absolute. Thus, at 15 lbs. inlet pressure, the water rate is approximately 23.6

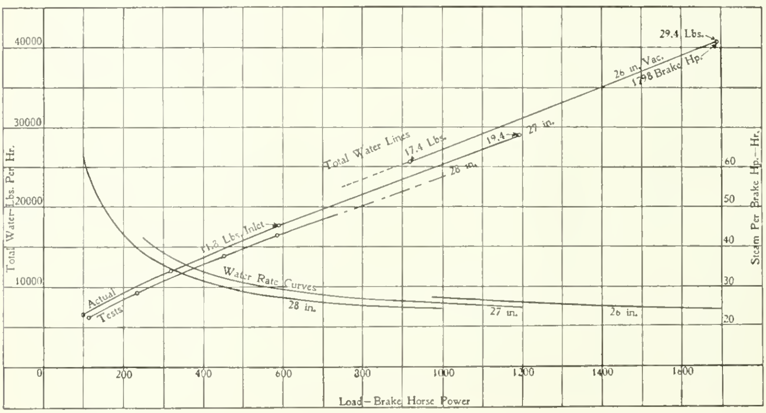


FIG. 5—RESULTS OF TESTS ON LOW PRESSURE SECTION OF 2 000 HORSE-POWER STEAM TURBINE

lbs. per brake hp-hr. (33.2 lbs. per kw-hr.), and at 20 lbs. inlet pressure, about 21 lbs. per brake hp-hr. (30 lbs. per kw-hr.).

The effect of higher inlet pressures and varying vacuua, is well shown by Fig. 5, a series of tests upon the low pressure section of a 2 000 hp. lighting turbine built for the Interboro Rapid Transit Company in 1902. This machine is of the single-flow design, the high pressure section expanding to about atmosphere and the low pressure section below. Note that the water lines are virtually straight up to the maximum initial pressure, 30 lbs., and slightly divergent for varying vacuum. This range of inlet pressure represents quite closely the actual range of operation in a combined engine-turbine plant. The result of tests on this machine, the first

one of this type built for commercial service, shows an efficiency ratio (percent of Rankine-Clausius cycle) of about 70 percent at 15 lbs. absolute inlet pressure and 27 inches vacuum. And this may be improved upon if it is considered expedient to design for higher vacuum.

CHARACTERISTICS OF LOW PRESSURE TURBINE

From a thermodynamic standpoint, the low pressure turbine is the exact counterpart of familiar complete expansion turbine, and it possesses the same characteristics, as shown by Fig. 5. As in the high pressure turbine, the line of total consumption per hour, or water line*, is practically straight, resulting in a constantly decreasing water rate curve. The power developed by this machine increased in proportion to the inlet pressure, barring the small friction drop throughout the machine at no load. As this type of machine employs no mechanism in the shape of overload or secondary valves, this was to be expected and the water rate curve is necessarily an equilateral hyperbola. The low pressure turbine may be regarded as the third cylinder of a triple expansion system, and is equivalent to such cylinder fitted with fixed cut-off. In other words, it must have a definite initial pressure to enable it to pass a given weight of steam. This necessitates a careful study of engine cylinder proportions and valve movements. For when direct-connected to an engine, the release pressure in the low pressure engine cylinder may be well above the initial pressure required by the turbine, or considerably below it, depending upon whether the load is heavy or light. In the first case, a large receiver drop would ensue between engine and turbine, and in the second, a serious loop in the low pressure card. Hence, the type of engine, cylinder ratio, the cut-off and the average and maximum load demand must be known before any rational decision can be made as to the proper size of turbine to install and the resulting distribution of load predicted. However, should errors be made in the calculations or determinations of the low pressure turbine characteristics, the same can be easily rectified by a slight change in the angle of the blades, at a very small expenditure.

ENGINE CHARACTERISTICS

Assuming a Corliss compound engine of normal design, there are two methods of governing to be considered:—

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*Sometimes called the Willans Law.

a—High pressure cut-off variable; low pressure fixed.

b—Parallel cut-off; i. e., both high pressure and low pressure variable in the same direction, increasing with the load.

The parallel system is widely employed in Corliss practice to maintain an equalization of work in the two cylinders. It is difficult, however, to avoid loops in the low pressure cards at light loads non-condensing, as the low pressure cylinder expands below the exhaust pressure. In case *a* the low pressure cut-off is deliberately fixed far enough in advance to eliminate the low pressure loop in the lower ranges of loads anticipated. But this system has the disadvantage of causing a great disparity in loading of high pressure cylinder. Thus with low pressure cut-off fixed at 75 percent of stroke and the high pressure as short as 15 percent, the engine would deliver steam to the turbine at 8 lbs. absolute and without loop. But on maximum load with high pressure cut-off at 75 percent and

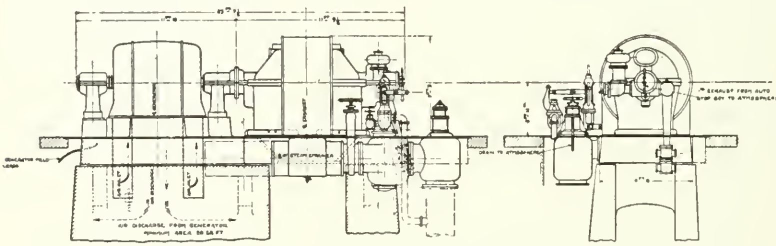

FIG 6—SECTION OF 2 000 HORSE-POWER LOW PRESSURE STEAM TURBO-GENERATOR SET

25 lbs. back pressure, the ratio of work in the two cylinders would be about two to one.

A point worth noting is that in a lightly loaded plant where a large increase is anticipated, the low pressure loop may be to some degree avoided by omitting a few rows of turbine blades, thus enabling it to pass the same quantity of steam at a lower inlet pressure. Ordinarily two rows will be sufficient and these may be replaced later when normal operation is resumed.

This brief description will serve to illustrate the necessity of a careful study of the engine problem. In designing a plant for a given load factor; say 75 percent average, 150 percent maximum rating; the point of rating of the combined unit may be regarded as corresponding to the point where the engine is operating at its best economy non-condensing.

Gary Installation—A typical example of a low pressure turbine

application is found in the plant of the U. S. Coal & Coke Co., Gary, W. Va. It operates the mining property, serving hoists, pumps, blowers, lights, etc. The plant contains two 24″ by 44″ by 42″ Corliss engines, direct-connected to 750 kw generators, one 1 000 kw complete expansion steam turbine set and a 1 000 kw low pressure steam turbine set, both of the Westinghouse-Parsons type. These turbines are served by three fan-driven cooling tower units, each 24 feet in diameter and 25 feet high. The following figures

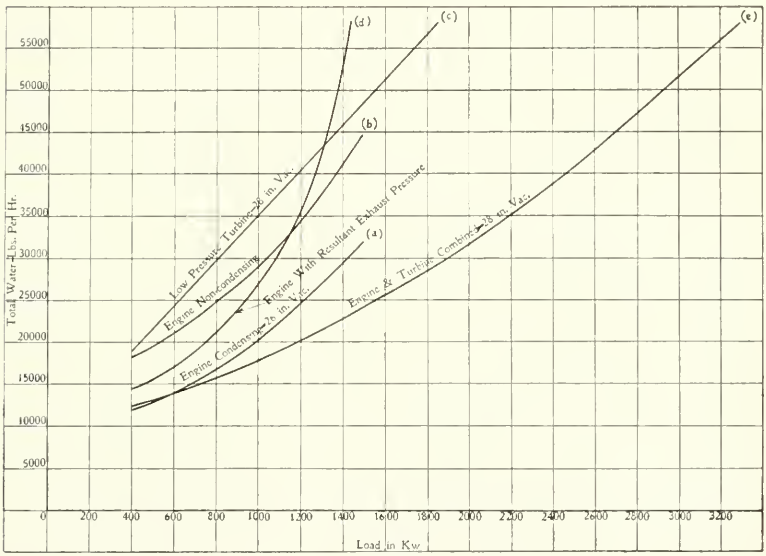

FIG. 7—CURVES OF TOTAL WATER PER HOUR FOR 28 AND 54 BY 48 INCH CORLISS ENGINE AND LOW PRESSURE TURBINE.

roughly indicate the normal operation of the generating units from readings taken Oct. 7, 1908:—

Output of two Corliss engines	1400	kw.
Output of low pressure turbines	1200	kw.
Steam pressure (gauge)	150	lbs.
Vacuum, L P turbine (referred to 30″ barometer)	25.8	in.
Temperature of injection	88	deg.
Temperature of air	85	deg.
Range of cooling in tower	31	deg.

Thus, the low pressure turbine carried a little less than half the total load on less than 26 inches vacuum, and would have carried over 1 500 kw on 28 inches vacuum with better condensing condi-

tions, giving a probable water rate for the engine-turbine plant of approximately 18.5 lbs. per kw-hr.

Combined Plant—The effect of these various factors may be best explained from Figs. 7 and 8 which have been prepared to illustrate the principles of design for a 2 000 kw installation suited to a 50 percent overload, or thereabouts. Fig. 7 shows only the water lines, from which are derived the respective water rate curves, Fig. 8. These water lines cover the following conditions:—

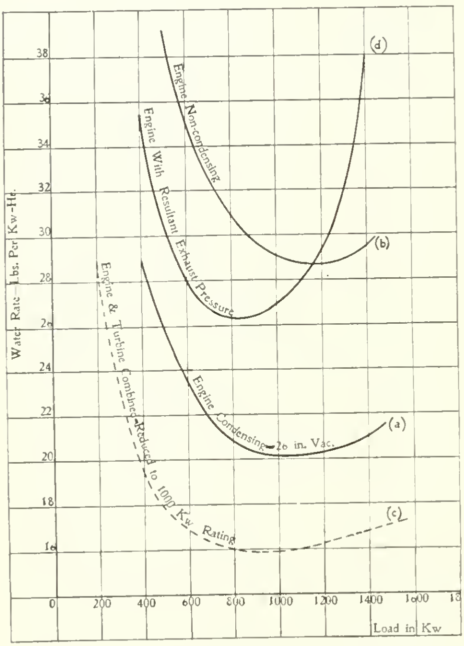

FIG. 8—CURVES OF WATER RATES FOR 28 AND 54 BY 48 INCH CORLISS ENGINE AND LOW PRESSURE TURBINE

a—Engine alone, condensing, 26 inches vacuum.

b—Engine alone non-condensing, 17 lbs. absolute back pressure.

c—Low pressure turbine alone, 28 inches vacuum, variable inlet pressure.

d—Engine non-condensing with variable back pressure, resulting from its connection to to the turbine.

e—Combined engine and turbine system, 28 inches vacuum.

Of the above, *a*, *b* and *c* were obtained by actual data. The combined curve *d* must be found graphically from the engine and turbine characteristics, and the final curve *e* by combining *c* and *d*. These water lines, Fig. 7, serve to illustrate the difference between the "Willans" characteristic for a turbine and that for an engine governed by cut-off. One is a straight line, the other a curve. The turbine has no point of lowest water rate other than maximum load; the engine ordinarily does its best at rating or under. It is usual practice to rate an engine at the point at which its rate of steam consumption is lowest. This may be found from the water line at the point of tangency of a radial line from the origin. Thus, this

engine running condensing shows its best economy at about 1 000 kw, and non-condensing, at about 1 200 kw, which is entirely rational. On the other hand, the resultant engine curve *d* shows a best point of economy slightly under 900 kw, due to the influence of the variable back pressure. Therefore, the turbine should be designed to pass just the amount of steam required at a back pressure corresponding approximately to this point of best engine economy non-condensing. Care must be used, however, in adapting the turbine to the engine, to avoid any condition that will cause excessive pressures on engine crank pins and bearings.

This point of safe pressure is mentioned because of a tendency to permanently overload the engine in the desire to produce a very low water rate. It should not be considered good practice to operate an engine on pressures much in excess of 50 percent over that for which it was designed*. A recent study of a combined plant that has been widely published, shows that in order to obtain a low combined water rate, 15.2 lbs., the engine had been forced to an m.e.p. of 56 lbs. referred to the low pressure cylinder. In the typical study, Figs. 7 and 8 it has been thought best to take an engine of normal proportions, as found in many lighting and traction plants (cylinder ratio one to 3.75) rather than a ratio more suited to efficient non-condensing operation; e. g., one to 2.5 or 3, hence the results may be considered conservative in this respect. The design is based on, (1st) an engine rating (best) of about 33 lbs. m.e.p. referred to low pressure cylinder, 165 lbs. absolute boiler pressure, and 17 lbs. absolute back pressure, and (2nd) allowing one pound drop between machines, the turbine passing the engine steam at 16 lbs. inlet pressure, 28 inches vacuum. The combined plant, 2 000 kw, has an overload capacity of 50 percent with some excess margin.

By examining the water rate curves, Fig. 8, it will be found that the engine gives an economy of 20.05 lbs. per kw-hr., condensing, 28.8 lbs. per kw-hr. non-condensing, for a normal load of 1 000 kw in each case; but in combination with the turbine, a maximum water rate of 15.8 lbs. per kw-hr. At rated load, the combined plant shows an improvement of 22 percent in water rate. At light loads, however, the combined plant ceases to be as efficient as the engine running alone condensing. The point is, of course, somewhat variable, as it is difficult to locate accurately from two curves at such an

*In average practice, a compound Corliss engine (condensing) would be designed for about 30 lbs. m.e.p. at rating, and should operate with a m.e.p. much over 45 lbs. referred to low pressure cylinder.

acute angle; but it seems probable that in the practical operation of a combined plant, it is desirable to shut down the low pressure turbine when the load falls below 30 percent rating, for example, and operate the engine alone.

GOVERNING

For a study of governing the various classes of service may be summarized as follows:—

Class A—Turbine electrically locked with engine; that is, serving same bus-bars.

1—Turbine taking all of engine steam. No governor required. Load on turbine varies with engine load.

2—Turbine taking part of engine steam. No governor required. Output remains practically constant, with uniform pressure in exhaust mains due to excess supply of steam.

In both the above cases, atmospheric relief valves should be provided, if only to enable the engine to operate while the turbine is shut down.

Class B—Turbine electrically independent of engine; that is, serving separate bus-bars.

3—Turbine taking all or part of engine steam. Governor required in case of intermittent supply.

In case of deficiencies of long duration, but with rapidly fluctuating supply averaging in excess of the demand, a regenerator may become profitable, or the equivalent in electrical storage may be used in connection with a direct-current system.

In all of these cases, a safety stop is obviously essential simply for insurance against possible overspeeding. In *Class A 2*, for example, should the circuit breaker open with the turbine under load, the safety alone would prevent trouble. The automatic safety stop may operate either a butterfly valve or a positive closing throttle.

AUXILIARIES

Inasmuch as the turbine is dependent upon auxiliaries, it is pertinent to point out some facts in this regard. If the ideal water rates of a turbine expanding from atmosphere down to various vacuua be compared, it will be found that while the ideal machine improves continuously down to the lowest condenser pressures, the actual turbine cannot make as good use of the last inch or two of vacuum, as in other parts of the expansion range; in other

words, the highest efficiency* may be expected in moderate ranges of vacuum. Assuming that the turbine improved five percent per inch vacuum around 27 inches, it is plain that an efficient condenser is very desirable, but with warm circulating water it is not always possible to obtain the vacuum desired. This is due almost always to the inability of the condenser to work with a *small enough temperature difference between steam and discharge water.* A condenser may be regarded as a heater and its effectiveness is entirely dependent upon its ability to deliver water heated as near as possible to the temperature of the steam. This is of the utmost importance in plants where cooling towers are necessary. And at this point may be emphasized the fact that the cooling tower is rapidly receiving the recognition it deserves. This has been brought about by the recent development of more efficient condensing apparatus.

A good surface condenser should operate to at least within 15 degrees difference between the temperature of the steam and discharge water; a good barometric jet within ten degrees, yet in some power plants twice this difference is tolerated as supposedly good performance. This is the secret of the poor vacuua against which turbine builders are obliged to struggle in designing machines for better conditions.

There are now on the market condensers of the jet type which are able to operate within two to five degrees of the steam temperature and without unusually bulky or wasteful auxiliaries. This considerably reduces the quantity of cooling water necessary to condense a given amount of steam; and is especially applicable to cases where condensing conditions are unfavorable. The determination,from a commercial standpoint, of the most economical vacuum for a given unit, involves a careful consideration of the variation in economy and cost of the auxiliary equipment necessary to obtain the different vacua.

It is important to deliver steam to the turbine as dry as possible owing to the well known effect of moisture in decreasing the output through friction. The quality of steam from the engines is, of course, indeterminate and varies between wide limits. So that a separator had best be installed in the exhaust main before the steam reaches the turbine. This also serves to remove the water of condensation where the exhaust piping is long. This necessity suggests the use of a moderate superheat in the engine, sufficient to

*Efficiency ratios are meant here. The water rate of course improves steadily with higher vacua.

insure dry steam at the turbine. This would avoid the resistance through the separator, which may be a serious matter in dealing with large piping and high velocities. The only other alternative is the use of drying coils in the exhaust main. This, however, has proven to be decidedly uneconomical if live steam is used for this purpose. It could only be applied in cases where some form of waste heat could be used to advantage.

SUMMARY

The most important thoughts presented in the preceding, may be summarized thus:—

1—Low pressure turbine application is exceedingly flexible, and may be worked to advantage into existing engine plants of good, as well as poor design, in conjunction with engines of high as well as low expansion ratio.

2—Regenerative accumulators are not always essential in low pressure turbine work; in fact, ordinary power plant work does not require their use.

3—It is important to choose proper turbine sizes so as to permit good economy in engines and maintain exhause pressure above atmosphere during normal loading, thus preventing air leakage in valves and piping.

4—The inherent efficiency of a combined plant is greatest at moderate vacua, 70 to 73 percent of the Rankine-Clausius cycle.

5—The weight and cost of a low pressure turbine unit is not far from that of the complete expansion unit.

6—No governor is required if the turbine is electrically connected to the engine and takes all or part of the steam.

7—Efficient safety overspeed stop devices are necessary.

THREE-PHASE—TWO-PHASE TRANSMISSION BY STANDARD TRANSFORMERS

L. A. STARRETT

THE method of transforming from a three-phase circuit to a two-phase circuit by the use of two transformers provided with suitable connections from the windings, is well known. The usual connections are shown in Fig. 1.* In certain cases standard transformers may be used for making this transformation.

A case was recently called to the attention of the writer in which it was desired to operate some 220 volt two-phase motors from the secondary circuit of a 4 000 volt, three-phase system. There were available standard transformers having a normal ratio of 2 200 to 220 volts, in which extra terminals were brought out so that a ratio of 2 000 to 222 volts could be obtained. The primary winding fo these transformers was in two parts which could be connected in series for 2 200 volts or in parallel for 1 100 volts. In transformers designed for changing a 4 000 volt three-phase circuit to two-phase, one of them is provided with a terminal at its middle point which will give an e.m.f. of 2 000 volts between this middle point and each outside terminal, and the other is adapted to receive 86.6 percent of 4 000 volts or 3 465 volts as shown in Fig. 2.

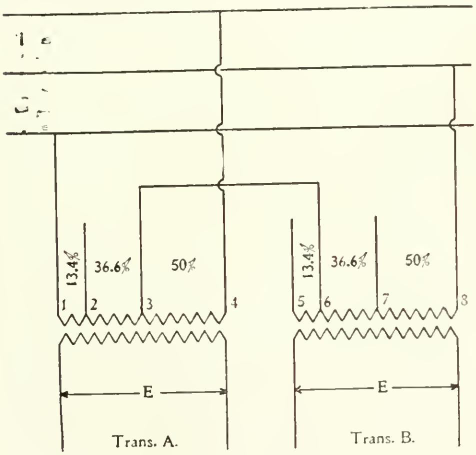

FIG. 1.

Instead of the 4 000 volt transformer, two 2 000 volt transformers may be connected in series and their point of connection used as the middle point for the T-connection. It is obvious that two transformers connected in this way, as shown in Fig. 3, may be used satis-

*See also article on "Three-Phase—Two-Phase Transformation," by Mr. E. C. Stone, in the JOURNAL for October, 1907, p. 598.

factorily. In the usual three-phase T or three-phase—two-phase connection, the current in primary of the second transformer divides on reaching the first transformer and flows equally in both directions from the middle point or point of connection to the line terminals. These two equal currents pass around the transformer core in opposite directions, thereby neutralizing the magnetic effect and preventing a choke coil action. If the two halves of the winding be on separate and magnetically independent cores, this neutralization does not occur and they will act as choke coils and unduly reduce the e.m.f. on the second transformer. One method of using two cores for this purpose would be to divide each half of the winding between the middle point and the outside terminals into two transformers. This would insure the neutralization of self-induction, as each transformer core would receive current from the second transformer flowing in opposite directions through the two windings of its primary circuit. While such connection can in some cases be made, it has some disadvantages, as it complicates the connections and may bring undue voltages between the different parts of the winding in the transformers. Another method of magnetically linking transformers is to connect the secondary windings in parallel. Any tendency for difference of phase between the two transformers will then be resisted by a flow of corrective current through the secondary coils.

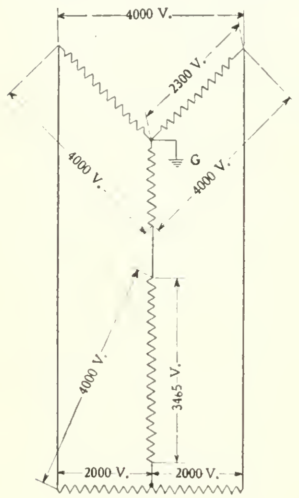

FIG. 2.

In the case in had, two transformers, each having a ratio of 2 000 to 222 volts may be connected across the 4 000 volt circuit with their primaries in series and their secondaries in parallel as indicated at 1 and 2, Fig. 3. Under these conditions, the junction between the two primary windings may be used for connecting to the primary of the second transformer in the T-connection as shown in Fig. 3.

The next requirement is that the second transformer be adapted for receiving 3 465 volts and delivering 220 volts. If two transformers connected for 2 200 volts and 1 100 volts, respectively, be placed in series, they will be adapted for receiving 3 300 volts

and delivering 220 volts if their secondaries are connected in multiple. If instead of 3 300 volts, the primary e.m.f. be 3 465, the excess, 165 volts (which is almost exactly five percent), would give an excess of five percent, or approximately 230 volts on the secondary instead of 220 volts. A difference of five percent between the e.m.f. delivered to an ordinary two-phase motor is quite admissible. It will be seen that the transformer connected for 1 100 volts will need only half the capacity of the transformer connected for 2 200 volts in series with it, as the primary current is necessarily the same and the e.m.f. is half as great.

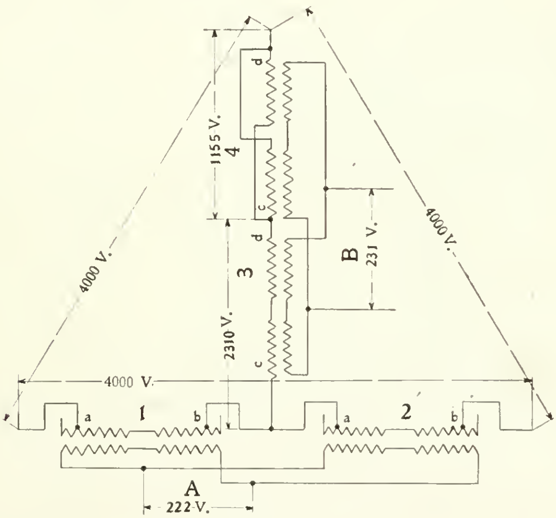

FIG. 3.

If a total output of 12 kw be required, the transformers for supplying the current to each phase of the two-phase circuit should have a capacity of six kw. The two transformers which are connected in series between two terminals of the three-phase circuit should have equal capacity, or three kw each. The ratio, as above explained, should be 2 000 to 222 volts. The transformers for the other phase should have capacities of four kw and two kw, respectively, the first having a normal connection for 2 200 to 220 volts, and the second having a normal connection for 1 100 to 220 volts. The primaries will be connected in series and the secondaries in multiple. The actual e.m.f., as above explained, will be about five percent high. If other outputs are required, standard transformers of proportionate output or the nearest size available should be used.

In general, it is preferable to secure two transformers of the required output and with windings designed for the three-phase—two-phase transformation rather than to employ four transformers in the manner above explained. The arrangement shown, however, may be conveniently employed in cases where only certain standard transformers are available.

It is obvious that the secondary windings might be connected for 110 instead of 220 volts, and also that if the transformer primary windings were adapted for half the e.m.f.'s above contemplated, they would be adapted for connection to a 2 000 volt circuit. With the secondaries connected for 220 volts, it is also possible to connect the middle points between the two secondary coils of the two transformers on each phase and thus secure from these connections a third wire in each phase by means of which 110 volts may be obtained between one of the middle wires and either of the other wires of the same phase. Such a connection can be used to advantage in starting induction motors if only a low starting torque is required. By this method no starting device is required with the exception of a four-pole double-throw switch. Some standard transformers are provided with both five percent and ten percent taps on the primary winding. With 2 000 volts applied to 85 percent of the primary winding of transformers 1 and 2, the secondary voltage would be 235. This arrangement would make the voltages on the two-phases even more nearly balanced.

FIG. 4—INSTALLATION OF FOUR STANDARD TRANSFORMERS CONNECTED FOR THREE-PHASE—TWO-PHASE TRANSFORMATION.

In Fig. 4 is shown an installation arranged as shown in Fig. 3, to furnish two-phase currents for some induction motors, which has been working for a number of months with entire satisfaction.

METER AND RELAY CONNECTIONS—(Cont.)

THREE-PHASE—THREE-WIRE CIRCUITS

HAROLD W. BROWN

THREE-PHASE circuits are of two classes, three-wire and four-wire, similar in operation and in their connections to transmission lines, but requiring different meter and relay connections. It is convenient to consider the connections for the two kinds of circuits separately. In the present article, therefore, will be considered various standard and special connections for three-phase—three-wire circuits, including the methods of grouping transformers, single-phase and polyphase meters, and also the connections required in using current and voltage receptacles in order

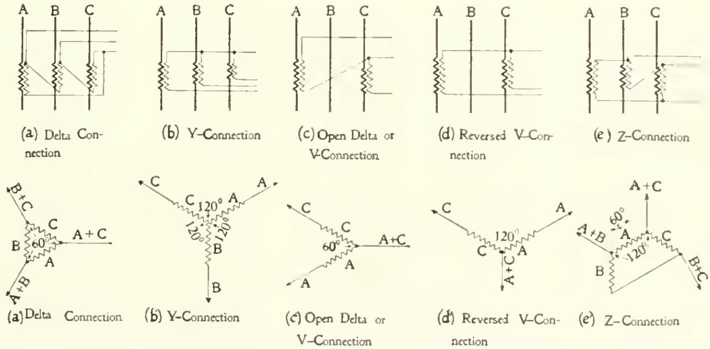

FIG. 1—SERIES TRANSFORMER CONNECTIONS AND VECTOR DIAGRAMS.

In the vector diagrams the zig-zag lines represent by their lengths and directions the magnitude and phase relations of the currents in the secondaries of the series transformers and likewise the straight lines represent the resultant currents in the meter leads.

to reduce the number of instruments required for the measurement of various combinations of two or more circuits. Systems having ground returns may be considered as equivalent to three-phase—four-wire circuits inasmuch as a ground return is in effect a neutral line. There is a fundamental difference between three-phase circuits and two-phase circuits in that in three-phase circuits each line serves as a return circuit for the others, whereas in two-phase circuits the current in the two phases are normally independent of each other. As has been the convention in previous articles of this series, rear view connections to the instrument are shown.

TRANSFORMERS

Series Transformers—The following points regarding the connections of transformers apply alike to three-phase—three-wire and three-phase—four-wire circuits. The primary circuits of the series transformers are, of course, connected in series in the mains of the

TABLE I—RELATIONS BETWEEN CURRENTS IN SERIES TRANSFORMERS AND IN THE LEADS RUNNING TO THE METERS.

CONNECTION	Connection between meter and transformers on:	Ratio of current in meter lead to current in one transformer.	Angle of lead* in degrees of this current relative to current in		
			A	B	C
Single transformer	A	1	0	+120	—120
Delta............	A and B	1.732	—150	— 30	+ 90
	B and C	1.732	+ 90	—150	— 30
	C and A	1.732	— 30	+ 90	—150
Y-Connection.....	A	1	0	+120	—120
	B	1	—120	0	+120
	C	1	+120	—120	0
	A, B and C	†0	Indeterminate		
Reversed V......	A	1	0	+ 120	− 120
	C	1	+120	− 120	0
	A and C*	1	—120	0	+ 120
Open Delta or V-Connection...	A	1	180	− 60	+ 60
	C	1	+120	− 120	0
	A and C	1.732	— 30	+ 90	− 150
Z-Connection.....	A and B	‡1	+ 120	− 120	0
	B and C	‡1.732	− 90	+ 30	+ 150
	C and A	‡1	+ 60	180	− 60

*This is the angle of lead in the case of one direction of rotation of phases, or the angle of lag in case of the other direction.

†With balanced loads the current in this line is zero. In case of unbalanced loads it is proportional to and in phase with the primary current in the neutral or ground return circuit.

‡This applies to the case in which the meter lead running to the transformers in lines *A* and *B* connects to the upper secondary terminals of these transformers, the meter lead to transformers *C* and *A* connects to the lower secondary terminals of these transformers and the meter lead to transformers *B* and *C* connects to the upper end of the secondary terminal of *C* and to the lower secondary terminal of transformer *B*.

transmission circuit. If three transformers are used, this is equivalent to a Y-connection of the primaries. The secondaries may be connected in several ways to give various desired results. The arrangements of secondary circuits in delta, Y, V, reversed V, and Z-connections are shown in Fig. 1; the same relations could be obtained by various other arrangements of the secondaries, but the principles would be the same. A combination winding and vector diagram corresponding to each type of connection is also shown in Fig. 1. The windings represent by their angles the phase relations between the various secondary currents. The phases and relative strengths of the resultant currents in the various leads are indicated by the lengths and directions of the straight vector lines.* In Table I are given the relative numerical values and phase relations

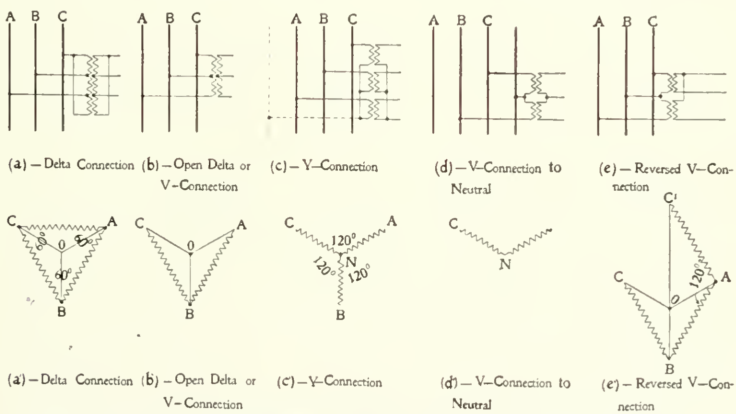

FIG. 2—SHUNT TRANSFORMER CONNECTIONS AND VECTOR DIAGRAMS.

In the vector diagrams the zig-zag lines represent the magnitude and phase relation of the e.m.f.'s in the single transformers. The straight lines *OA*, *OB* and *OC* represent, in each case, the magnitude and phase relations of the e.m.f.'s to neutral. In (e'), *OC'* represents the e.m.f. across the secondaries of both transformers.

of the resultant currents, assuming that the currents are equal in all of the transformers and that all the phase differences are equal; that is, that the phases are balanced.

With the "reversed V-connection" the currents in the three secondary lines are the same in strength and phase relation as in corresponding lines with the Y-connection, provided the primary is a three-wire circuit. Inasmuch as only two transformers are re-

*For fuller discussion of these and the following diagrams see article on "Vector Diagrams Applied to Polyphase Connections" in the JOURNAL for June, 1908.

quired in the reversed V-connection it is generally used in preference to the Y-connection, for three-wire circuits. Four-wire circuits require the Y-connection rather than the reversed V-connection.

Shunt Transformers—As shunt transformers have their primary circuits connected across phases, or from one line to neutral, the secondaries of the various transformers may be used either independently or connected together. Fig. 2 shows several of these connections, and the corresponding vector diagrams of secondary e.m.f.'s of the transformers. The e.m.f. between any two secondary lines in (a) and (b) is proportional to and in phase with the corresponding primary e.m.f. It is customary to make connections as in (b) because one less transformer is required than in (a). Similarly in (c) and (d) the secondary e.m.f.'s are proportional to and in phase with the corresponding primary e.m.f.'s between the various lines and neutral. Hence, in case the primary circuit has a neutral line and measurements of only two secondary e.m.f.'s are to be made, the connections are as in (d), thus using only two transformers; but if there is no primary neutral line, or if all three secondary e.m.f.'s are to be measured, connections are made as in (c). Connections as in (e) are not often used. One of the lines of the primary (*B* in this diagram) has connections to both of the transformers. The e.m.f. across the secondaries of both transformers (i. e., between *2* and *3* in the diagram) is in phase with the e.m.f. between line *B* and neutral. This secondary e.m.f. is 1.732 times that across the secondary of a single transformer. It is represented by *BC* in the vector diagram (e′).

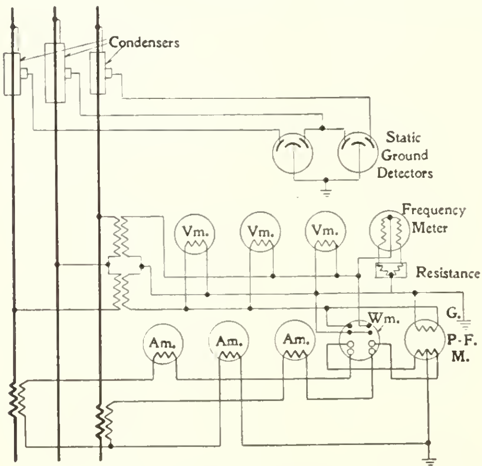

FIG. 3—GROUP OF METERS ON THREE-PHASE THREE-WIRE CIRCUIT.

Without the use of voltmeter and ammeter plugs.

GROUPING

A group of meters connected to a three-phase—three-wire cir-

cuit, without using plugs for shifting the voltmeter and ammeter connections from one phase to another, is shown in Fig. 3. Three ammeters, one wattmeter, and one power-factor meter are connected to the two series transformers; and three voltmeters, one frequency meter, and the wattmeter and power-factor meter already mentioned are connected to the two shunt transformers. Two single-phase static ground detectors are connected to the three lines by means of two condensers connected separately to the two ground detectors and a third condenser, larger than the other two, connected to both of the ground detectors.

Fig. 4 is a group of meters similar to Fig. 3, but having only one meter of each kind. The current is measured in each of the three lines by means of the three ammeter receptacles.

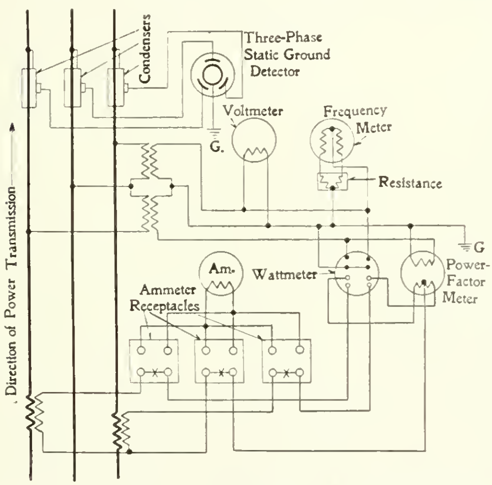

FIG. 4—GROUP OF METERS ON THREE-PHASE THREE-WIRE CIRCUIT USING AMMETER RECEPTACLES.

Voltmeter receptacles may also be used to connect the voltmeter across any phase.

POLYPHASE METERS

Power-Factor Meters

Fig. 5 shows three ways of connecting a three-phase power-factor and a vector diagram illustrating the phase relations of the various circuits. In No. *1* it is connected according to standard diagrams. If three phases follow each other in regular sequence, the meter will read correctly; but if the sequence of phases is reversed, the connections must be changed. It may be determined whether or not the connections as in No. *1* are correct by disconnecting the voltage circuit, when the pointer will rotate continuously. It should rotate in the *lead* (clockwise) direction; if it rotates in the *lag* (counter-clockwise) direction, the connections may be changed as in either No. *2* or No. *3*. It will then rotate in the right direction before the voltage connections are made and give the right indication after the connections are completed. In changing to No. *2* the right (as viewed from the rear) and middle series connections are interchanged, and the voltage

transformer is changed to a different phase. In changing from No. *1* to No. *3* the left and middle series connections are interchanged, and the voltage connections are interchanged. No change of voltage connections to a different phase is necessary in this latter case. The advantage of this method is obvious in the case of high-tension circuits. The change from No. *1* to No. *3* is also suitable for three-phase—four-wire and six-phase circuits.

In the vector diagram, Fig. 5, the proper phase relation of the left hand current circuit (as viewed from the rear) is represented by *L;* that of the middle circuit, by *M,* and that of the right hand circuit, by *R.* The phase of the voltage circuit is marked "Voltage." In meter No. *1* the currents in the left, middle and right hand currents circuits are in phase with those in the left, middle, and right hand primary lines respectively, and the voltage is in

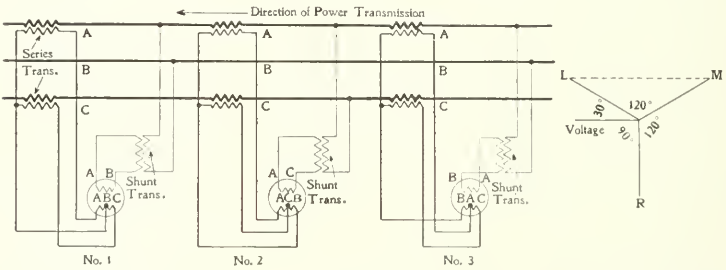

FIG. 5—THREE WAYS OF CONNECTING THREE-PHASE POWER-FACTOR METERS AND VECTOR DIAGRAM OF CURRENTS AND VOLTAGES.

Either No. 2 or No. 3 is correct if No. 1 is found to produce reverse direction of rotation.

phase with that between the left and middle lines. The vector for the voltage is, therefore, parallel to the dotted line *LM.* If the connections are changed to those of No. *2* the middle series terminal of the meter is connected to the transformer on the right hand line, and the voltage connection is between the left and right hand lines, so that the phase difference between the voltage and each of the currents in the meter is the same as before, but the sequence of currents in the current circuits is reversed, as shown by the order of the letters, *A, B, C,* of the current circuits. The phase differences are the same also in No. *3*, and the sequence of currents is the opposite of No. *1,* and the same as No. *2.** In all of these

*This will be seen by repeating the letters in the order in which they occur from left to right in No. *3*—*BACBAC.* This series includes *ACB,* which is the order of No. *2,* and it includes *CBA,* which is the reverse of No. *1.*

cases if the direction of power transmission were reversed, or if connections were made to the opposite ends of the series transformers the left and right hand voltage connections would be interchanged.

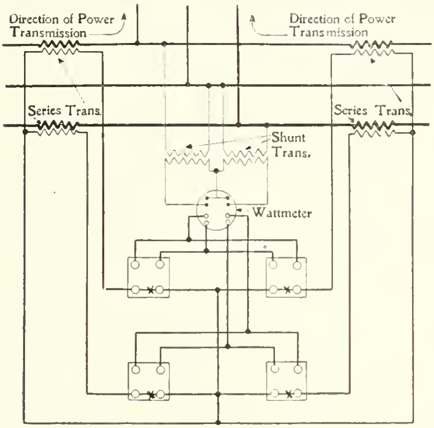

FIG. 6

Wattmeters—Fig. 6 shows a method of plugging by which a polyphase wattmeter is made to read the power transmitted over any of three branching circuits. With plugs in the left hand receptacles, the wattmeter measures the power transmitted over the circuit at the left, the positive direction of transmission being towards the right. With plugs in the right hand receptacles it measures power transmitted over the right hand circuit towards the left. With plugs in all the receptacles it measures the power transmitted inward over both the right and left hand circuits, which is the same as the power transmitted upward in the upper circuit.

As low scale readings are not as accurate as normal load readings, the method, shown in Fig. 7, of connecting a polyphase wattmeter, so that it will indicate double the actual power transmitted, is sometimes useful. As the series transformers are delta-connected, the current in each wattmeter current circuit is multiplied by 1.732, and the power component of the current is brought into phase with the corresponding voltage on the meter with the result that the meter will indicate exactly twice what it would with ordinary connections. This connection, however, introduces an error in case the currents in the three lines are not balanced.

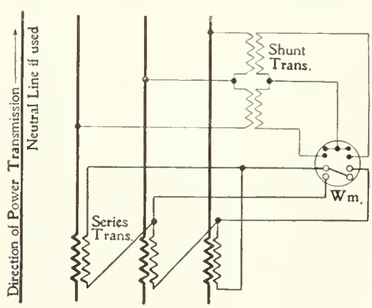

FIG. 7

(*To be continued.*)

CONTRIBUTORS TO THE JOURNAL FOR 1908

It has become customary at the end of each year to give brief notes regarding the contributors to the JOURNAL during the year. These items, while not intended to be complete, are intended to give our readers a more comprehensive idea of the great variety of technical talent from whom the contributions to the JOURNAL are obtained. As a number of the contributors for 1908 have also contributed during previous years, only their names and present positions are given. For more extended notices regarding these (indicated by a *) the reader is referred to the December issues of preceding volumes of the JOURNAL.

Since the character of articles appearing in the JOURNAL is somewhat different from those in other publications, very few reprints of articles appearing elsewhere will be found in the JOURNAL. The greater part of the articles are written by request especially for the JOURNAL.

As in other years, a considerable part of the contributors are members of The Electric Club, by which the JOURNAL is published.

*C. L. ABBOTT, erection department, Boston district, Electric Company.

L. M. ASPINWALL (Cheltenham Military Academy, Emerson Institute, Johns Hopkins Univ.) has been with the Electric Company nearly fifteen years, where he has been engaged on engineering work on underground traction systems, car equipment, multiple control, project work, and is now engaged on locomotive equipment and testing. He has been identified with single-phase railway work since the first motors were designed and tested in 1894.

*C. B. AUEL, manager railway department, Electric Company.

J. N. BAILEY served his apprenticeship with the Blaydon Iron Works Company; engaged in auxiliary and marine work for British and foreign admiralties, and on torpedo destroyer machinery at Palmers, Jarrow. Joined Parsons Marine Steam Turbine Company in 1898 as draughtsman, and was later assistant works manager, Liverpool representative, and chief of experimental department of C. A. Parsons & Company, Newcastle-on-Tyne. Joined the British Westinghouse Electric & Manufacturing Company in 1903.

*J. R. BIBBINS, technical writer, Westinghouse Machine Company.

M. N. BLAKEMORE (Williamson School, Drexel Institute) had his shop experience with several concerns in Philadelphia and was in charge of draughting room of Wm. H. Weston & Company for a year. He was in the engineering department of the Electric Company nine years and in the railway correspondence department three years, where he was in charge of the contract division and later specialized on single-phase work and electrification projects. At present he is employed in the office of the assistant to the first vice president.

*GRAHAM BRIGHT, railway division, engineering department, Electric Company.

HAROLD W. BROWN (Cornell Univ., '98, fellow in physics, Ohio State Univ., '00) has held the following positions: foreman, Church Envelope Company, Cleveland, O.; associate professor of mechanical and electrical Engineering, Delaware College; assistant profes-

sor of electrical engineering, Univ. of Pennsylvania; electrical engineer, Browning Engineering Company, Cleveland, O. Since 1906 he has been with the Electric Company as a meter and relay engineer.

G. W. CANNEY, formerly district engineer of the Electric Company at Chicago. At present their superintendent of erection.

N. A. CARLE, engineer, Westinghouse, Church, Kerr & Company, has been temporarily with Northern Colorado Power Company, Denver.

M. B. CHASE was engaged in the fire and police signal business from 1892 to 1896. He then spent three years in storage battery work, making a specialty of the application of storage batteries to dental and surgical work. In 1898 he entered the employ of the General Electric Company where he made a specialty of meters for four years, after which he was employed in the laboratory of the Edison Electric Illuminating Company of Boston for about a year. He entered the employ of the Electric Company in 1903 and is at present in the detail and supply department of the Boston office.

J. S. S. COOPER, M.A., B.SC., graduated at Canterbury College, New Zealand University. After leaving the university he spent several years in teaching mathematics and science. Joined the staff of Messrs. Noyes Brothers, in New Zealand, and became connected with the Westinghouse Company in 1905. Now engaged in the design of turbo-generators.

*A. W. COPLEY, detail and supply engineering department, Electric Company.

E. H. COSTER (graduate of the Chalmers College of Engineering, Gothenburg, Sweden) came to this country in 1896 and gained his first experience on power plant engineering with Sheaff & Jaastad, consulting engineers of Boston, and with the Boston Elevated Railroad. Later entered the employ of Westinghouse, Church, Kerr & Company. In 1901 and 1902, was assigned to assist the British Westinghouse Electric & Manufacturing Company in the design of the Mersey Railway and Neasden power plants. On returning to New York he resumed work in the engineering department of Westinghouse, Church, Kerr & Company.

R. W. CRYDER entered the dynamo test of the Electric Company in 1904 and later took up work in the drawing office. He was with the Western Electric Company for about two years and then returned to the construction department. Early in the present year he took his present position with the Guanico Centrale, Guanico. Porto Rico.

*W. A. DICK, designing engineer, power division, engineering department, Electric Company.

*C. R. DOOLEY, power division, engineering department, Electric Company.

*E. L. DOTY entered the Cleveland works of the Walker Company in 1897 as an engineering student. He was later transferred to the Pittsburg works of the Electric Company. In 1900 he was assigned to the construction department in New York City where he was located during the electrification of the Elevated Railway and the Subway. In 1905 he was transferred to the engineering department on turbo-generator and transformer work and later was district engineer of the Pittsburg office. Since 1906 he has been district engineer at the Buffalo office where he has been engaged principally in high tension work in the Niagara Falls territory.

*A. M. DUDLEY, in charge of induction motor designs, industrial division, engineering department, Electric Company.

W. L. DURAND (Stanford Univ., '07) worked as draughtsman for the New York Central Electrification and as sub-station operator for the New York Edison Company. At present draughtsman for the New York Steam Company.

R. N. EHRHART (Cornell Univ., '01) has been with the Westinghouse Machine Company since July, 1901, in the steam turbine department.

THOMAS FRASER gained his early experience with the General Electric Company, England. For the past five and one-half years he has been connected with the British Westinghouse Company. Four years of this time were spent in the testing department. The past eighteen months, engaged on special outside testing work.

H. H. GALLEHER (Ohio State Univ., '94 and '96) since 1898 has been with the Electric Company on research and testing work. At present he is foreman of the high tension testing department.

M. C. GODBE (Utah Univ., 1884 to 1888) was engaged in electrical contracting from 1890 to 1896, after which, until 1906, he was department engineer and superintendent of electric service of the Utah Light & Railway Company. At present he is a consulting engineer at Salt Lake City.

*F. W. HARRIS, section engineer on circuit breakers, fuses, etc., engineering department, Electric Company.

*E. M. HERR, first vice president, Electric Company.

R. F. HOWARD (McGill Univ., '01) took the engineering apprenticeship course at the Electric Company shops and then took up work in the construction department, first at New York and later at Pittsburg. At present he is with the Canadian Westinghouse Company as district engineer for the Montreal territory.

*ALEXANDER C. HUMPHREYS, president, Stevens Institute of Technology.

*R. P. JACKSON, engineer on protective apparatus, detail and supply division, engineering department, Electric Company.

*H. D. JAMES, section engineer, industrial division, engineering department, Electric Company.

*WALTER C. KERR, president, Westinghouse, Church, Kerr & Company.

L. H. KIDDER began work with the Electric Company in 1897 at Pittsburg and in 1900 took up construction work in New York. In 1902 he went west and was connected with a number of power transmission companies on the coast and in Mexico. In 1905 he again entered the construction department where he has been engaged in single-phase railway work until the present time, with the exception of one year with the Pittsburg & Butler Street Railway Company.

C. W. KINNEY (Worcester Polytechnic Inst., '99 and '05) after graduation, was in the testing department of the General Electric Company, later taking the position of assistant electrical and mechanical engineer for the Worcester & Southbridge Street Railway during construction. Since that time he has held the position of electrical engineer for the Page Electric Company and Coghlin Electric Company, engineers and contractors, which position he still holds.

*S. M. KINTNER, on single-phase motor work in the railway division, engineering department, the Electric Company.

*H. L. KIRKER, resident engineer in charge of electrification of the St. Clair tunnel.

*B. G. LAMME, chief engineer, the Electric Company, associate editor of THE ELECTRIC JOURNAL.

*P. M. LINCOLN, engineer in charge power division, engineering department, the Electric Company, associate editor of THE ELECTRIC JOURNAL.

H. G. MacDONALD (Univ. of Tenn., 1892-1897) carried on experimental work at the University for the U. S. Dept. of Agriculture, road traction tests. He was with the U. S. Weather Bureau for three years and in 1901 entered the employ of the Electric Company first as draftsman and then in the engineering department.

*PAUL MacGAHAN, meter engineer, detail and supply division, engineering department, Electric Company.

*MALCOLM MacLAREN, professor of electrical engineering, Princeton University.

*A. H. McINTIRE, editor and manager, THE ELECTRIC JOURNAL.

G. R. METCALFE (Stevens Inst. of Technology, '86) spent one year after graduation in practical shop work, after which he was employed as draughtsman with the Sprague Electric Ry. & Motor Company on railway work. On the consolidation of this company with the Edison General Electric Company, he was transferred to the construction department and was placed in charge of the erection of several electric railways in the United States and Canada. Mr. Metcalfe next held the position of editor of "Electricity," New York, for about five years and was afterwards technical editor of the

"Street Railway Review," Chicago, for five years. In 1905 he became editor of the "Technical World" and the Text-book Department of the American School of Correspondence, Chicago, and the next year was apointed editor of the publication department of the Electric Company, which position he now occupies.

J. EDGAR MILLER (Lehigh Univ., '93; P. G., '94), after graduation, began work with the New York Telephone & Telegraph Company and later was in various departments of the Siemens & Halske Electric Company of America. Since 1898 he has been with the Westinghouse interests, principally on railway engineering and construction work in Russia, Great Britain, Canada and South America, as well as in this country.

*WM. O. MILTON, Chicago Pneumatic Tool Company, Franklin, Pa.

H. N. MULLER entered the shops of the Electric Company in 1897. A little later he accepted a position in the laboratory of the Allegheny County Light Company, Pittsburg, where he assisted in the tests of this company and the Pittsburg Railways Company on the consolidation of the two companies. In 1903 he was made electrician of the company and organized a trained corps of men, and developed a system of records, maps, etc., for taking census of consolidated properties of the Monongahela Light Company, Oakmont & Verona Light, Heat & Power Company, Ohio Valley Electric Company, and Southern Heat, Light & Power Company, representing the present system, obtaining first official information as to routes of circuits, sizes of conductors, location of loads, drops at various points, name and location of each customer, name and location of each piece of apparatus in each station and on the lines, character of construction, etc. In 1904 was appointed engineer of tests, extending the scope of the laboratory in the testing and repair of all apparatus purchased by the company, and materials and supplies used on the system. In 1905 he was appointed electrical engineer for the company, which position he holds at the present time.

*WILLIAM NESBIT, New York district office, the Electric Company.

*F. D. NEWBURY, engineer on alternating-current machinery, power division, engineering department, Electric Company.

N. C. OLIN went through the testing department of the Electric Company and afterwards was in the erection department. At present with Stanley Company, New Britain, Conn.

*J. S. PECK, consulting electrical engineer, British Westinghouse Electric & Mfg. Company, associate editor, THE ELECTRIC JOURNAL.

F. W. PRINCE (Trinity College, '00), after graduation, accepted a position with the Hartford Electric Light Company and has been with the company ever since as head draughtsman, switchboard constructor, superintendent of construction, and his present position of superintendent of their meter, arc lamp and inside construction department.

*K. C. RANDALL, engineer in charge, transformer division, engineering department, the Electric Company.

M. H. RODDA took a four-year apprenticeship course with the Electric Company, after which he attended the Ohio State University. In 1905 he entered the erection department of the Electric Company and is now located at the Philadelphia office.

*B. P. ROWE, switchboard engineer, power division engineering department, the Electric Company.

*M. C. RYPINSKI, salesman, New York district office, the Electric Company.

C. H. SANDERSON (Ohio State Univ.) has been with the Electric Company for the past eight years. Part of this time was spent in the factory, part in the draughting room and the last four years in the engineering department, where he is now engineer on switchboard and power station design.

*CHAS. F. SCOTT, consulting engineer, the Electric Company.

*C. E. SKINNER, engineer in charge, research division, engineering department, the Electric Company. Associate editor, THE ELECTRIC JOURNAL.

*E. H. SNIFFIN, vice president and sales manager, Westinghouse Machine Company.

L. A. STARRETT (Case School of Applied Science) was employed first

with the old Walker Company at Cleveland. In 1901 he entered the draughting department of the Electric Company, and later was in charge of transformer test and as inspector. He was with the Rust Boiler Company for one and one-half years. He entered the sales department of the Electric Company in 1907 and was assigned to his present position in the Pittsburg office.

*N. W. STORER, engineer in charge, railway division, engineering department, the Electric Company, associate editor, THE ELECTRIC JOURNAL.

R. W. STOVEL (McGill Univ., '97 and '00), after graduation, spent five years in Pittsburg, part of the time as electrical engineer with the Pittsburg & Lake Erie Railroad and the remainder with Westinghouse, Church, Kerr & Company. Since 1903 he has been in the New York office of the latter company, where he has had charge of several engineering operations of considerable magnitude.

ALEXANDER TAYLOR entered the employ of the Electric Company in 1888 in the winding department, where he remained until 1891, at which time he was transferred to the storeroom. Later he was connected with the purchasing department. In 1897 he was placed in charge of the Allegheny foundry, and in 1901 he was made superintendent of foundries. In 1902 he was appointed superintendent of production, which position he held for about a year, when his title was extended to superintendent of production and stores. He was made superintendent of the East Pittsburg works in 1905 and shortly afterwards was appointed acting manager of works in the absence of Mr. Philip A. Lange, who was called to the Manchester works of the British Company. In June, 1906, Mr. Taylor was made manager of works in charge of the East Pittsburg, Cleveland, Allegheny and Newark works, his present position.

A. A. TIRRILL, engineer, power and mining department, General Electric Company.

W. S. VALENTINE (Cornell, '00) taught two years in Pratt Institute and has since been with Westinghouse, Church, Kerr & Company as an engineer in the railway department. He originated the graphical method of plotting speed-time curves.

K. E. VAN KURAN (Univ. of Washington, '04), after being with the Seattle Electric Company for some time, took the Electric Company's engineering apprenticeship course and then accepted his present position in the contract division of the power department.

H. E. WAGNER (Penn. State College, '99), after graduation, was an engineer with the Illinois Central Railroad and later with the Missouri Pacific Railroad in the capacities of chief of party on location of new lines, resident engineer in charge of construction and division engineer in charge of maintenance of way. He was with the Electric Company during the electrification of the New York, New Haven & Hartford Railroad, after which he was with Messrs. Edwards & Zook, consulting engineers, engaged in the valuation of steam railroads. At present he is resident engineer with the Delaware and Western Railroad.

*B. WILEY, commercial engineer on steel mill equipments, the Electric Company.

LEONARD WORK took a two-years' apprenticeship course in an Edison central station. After a four-year technical course in Buffalo he studied abroad for a year. Subsequently he was chief electrician for a large manufacturing company. He resigned this position to enter the erecting department of the Electric Company.

*F. E. WYNNE, on project work, railway division, engineering department, the Electric Company.

F. A. WARFIELD, with the Bullock Electric Company for some time, and later was with the Denver office of the Electric Company.

*H. W. YOUNG, sales manager, Central Electric Company, Chicago.

THE JOURNAL QUESTION BOX

Our readers are invited to make use of this department to assist them in obtaining information regarding points which will be of value to them. As in any department of this kind the topics should be of general interest and of the kind that can be treated briefly. If a personal reply is desired in advance of publication a stamped return envelope should be enclosed.

All questions should be addressed to The Journal Question Box, care of The Electric Journal, Box 911, Pittsburg, Pa.

179—CURRENT TRANSFORMER SECONDARIES CONNECTED IN MULTIPLE OR SERIES—Two feeder circuits operating from single-phase bus-bars have series transformers connected as shown in Fig. 179(a), the secondaries being connected to ammeters. Ammeters *A* and *B* measure the current in the separate feeders. If it is desired to record the total power by means of a totalizing ammeter, can connections be made as shown in Fig. 179(a) or as shown in Fig. 179(b) for this part of the circuit, assuming that there is a current of 1 000 amperes in feeder *1*, and a current of 500 amperes in feeder *2*? W. H. B.

The multiple connections shown at *A* in Fig. 179 (a) will record the total power in the two feeder secondaries provided the ratios in the two series transformers are identical. It is obvious that a meter cannot be calibrated for operation on two series transformers connected in

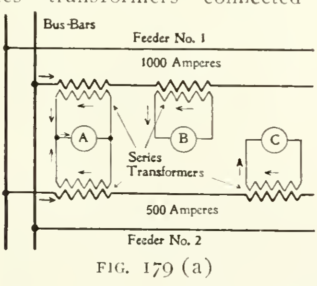

FIG. 179 (a)

multiple if these transformers have different ratios. Instantaneous directions of currents in the secondary circuits are as shown. With currents in the two feeder circuits, as in Fig. 179 (a), the totalizing ammeter would indicate 1 500 amperes, and with no load in feeder No. 2, and a current of 1 000 amperes in feeder No. 1, the ammeter would, of

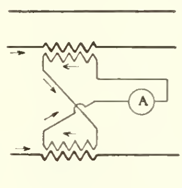

FIG. 179(b)

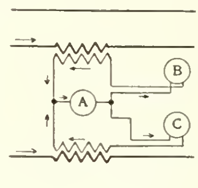

FIG. 179 (c)

course, indicate 1 000 amperes. With the secondaries of the two transformers connected in series, as shown in Fig. 179 (b), the ammeter would register correctly under one condition only, viz., when the secondary currents in the series transformers are equal; otherwise this method of connection would not give even approximately accurate results. It is interesting to note that ammeters *B* and *C*, shown in Fig. 179 (a) connected to separate series transformers, could be connected to the transformers as in Fig. 179 (c), and give equally accurate indications. P. M.

180—STARTING SINGLE-PHASE INDUCTION MOTORS—In a single-phase induction motor with squirrel-cage type secondary, and having a primary winding without an auxiliary or split-phase winding, how is the accelerating torque derived when the motor is being started? I have seen a two hp motor directly connected to the line and started by giving it a few turns by hand, there being no load on the motor. Please explain. V. J. C.

The magnetic field set up by the current in the primary winding so acts on the secondary or squirrel-cage winding as to cause a resultant field to be induced in the secondary at an angle of 90 electrical degrees. The magnetic field in the secondary (rotor) in turn acts on the iron of the primary so that in the primary there are two alternating magnetic fields, one due to the current in the primary winding and the other due to the field resulting from the transformer action of the secondary. The resultant of these two fields forms a revolving field in the primary which is virtually the same as the revolving field in a two-phase motor. If now, the rotor be given enough of a turn by hand to allow this transformer action to start, a torque is immediately set up, which causes the motor to speed up, which in turn increases the transformer action between the primary and secondary windings and this in turn builds up the torque until the motor "pulls into step." The torque is not sufficient to make it possible to start a motor under load in this manner; accordingly motors are arranged either with the terminals of the windings so arranged that an auto-starter may be connected (the primary winding being divided into two parallel circuits, thus "splitting the phase" during starting) or a split-phase winding is supplied in the primary of the motor. The phenomena of single-phase magnetic fields are explained at some length in Vol. II. of the JOURNAL, p. 488, in an article by Mr. B. G. Lamme.

181—AYRTON SHUNT—Please explain by mathematics the electrical principle of the operation of the Ayrton shunt.

R. G. H.

A form of universal shunt for use with galvanometers to increase or decrease their sensibility and thus increase the range of their application has been developed by Ayrton and Mather. It is described and its principles explained in Foster's Handbook, p. 29, and in the Standard Handbook for Electrical Engineers, p. 65. It may be stated briefly as follows: In Fig. 181 (a), let G equal the resistance of the galvanometer, S the resistance of the shunt; then, the joint resistance of the two is $GS \div (G+S)$. If I equals the total current flowing in the circuit and I^1 equals the part flowing through the galvanometer; then, $I \div I^1 = (G+S) \div S = G \div S + 1$ equals the multiplying power of the shunt. The

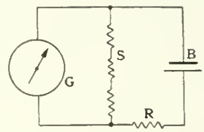

FIG. 181 (a)

resistance of a shunt which will give a certain multiplying power, n, is equal to $G \div (n-1)$. Manufacturers of scientific instruments such as Leeds & Northrup, Phila., Pa., publish descriptions of this device giving complete explanation of its principle and method of operation. H. B. T.

182—IRON WIRE FOR TRANSMISSION LINES—In transmission lines which are comparatively short and in which the power transmission is small, is it not desirable to use iron wire in place of copper? I know of several companies operating in Mexico that are using 15 000 volts for distribution, this being stepped down to 440, 220 or 110 volts on the customer's premises. The main line is of course built with copper wire, but owing to the peculiar way in which the customers are distributed over some of the districts, it is sometimes found necessary to build long branch lines, say 5 or 6 kilometers in length. For this kind of work the iron wire seems to give the most economical results.

A. J. K.

There are special cases where it is desirable to use iron wire but it is not economical unless the size of copper wire which would give the permissible drop is considerably smaller than that necessary for mechanical strength. For instance, if a No. 20 copper wire would not cause too great a drop in voltage it would be enconomical to use iron wire because, for mechanical reasons, such small copper wire is not

suitable. The resistance of iron wire to alternating currents is higher than for direct currents, and this must be taken into account when calculating the proper size of iron wire. No very reliable data is available for calculation of this resistance; different authorities giving widely varying values. A value of one and one-half to three times the resistance to direct current is probably approximately correct for ordinary sizes of iron wire at 25 cycles. The larger the wire, the larger the ratio of alternating-current resistance to direct-current resistance. For higher frequencies larger ratios must also be allowed. If a value of 2 be assumed for this ratio, the resistance of a given size of iron wire to alternating current is about 20 times that of the same size of copper wire. Assuming a case, where, for all electrical purposes, No. 20 copper wire would answer, while for mechanical reasons No. 8 should be used; an iron wire having the same resistance to alternating-current as a No. 20 copper wire would be 20 times this size, *i. e.*, No. 7. It would obviously be more economical to put in a No. 7 iron wire than a No. 8 copper. Of course such cases as this appears only when the amount of power to be transmitted is small. A. W. C.

183—TRANSMISSION LINE PROBLEMS—In an article in Vol. II., p. 361, of the JOURNAL, Mr. J. S. Peck gives a short method for calculating the regulation of alternating-current lines. I have tried to work out several problems by the method given, but none seems to check with the results obtained by using the longer formulas. Please give an example of a practical problem showing the results obtained by the use of the two methods. A. J. K.

The method described in Mr. Peck's paper for calculating the regulation is only an approximation, but is close enough for most practical purposes. The problem which he works out is as follows: Power-factor of load, 80 percent; Ohmic voltage, ten percent; Reactive voltage, 14 percent; reactive factor $=\sqrt{1-0.8^2}=0.60$. In order to find the regulation, the ohmic voltage is multiplied by the power-factor and the inductive voltage by the reactive factor of the load. The sum of the products is the total drop. This gives $(10\times0.80)+(14\times0.60)=16.4$ percent. The ohmic voltage is the voltage drop in the line *in phase* with the current and the reactive voltage is the voltage drop in the line *in quadrature* with the current. Working this problem out by the longer and more exact method, the solution is as follows: The voltage across the load which is in phase with the current is $0.8e$, where e is the total voltage at the load. Adding to this value, 10 which represents the ohmic voltage drop in the line, gives $(0.8e+10)$ as the component of the line voltage which is in phase with the current. The component in quadrature to the current is the reactive voltage drop in the line, 14, plus the reactive voltage in the load, which is $0.6e$, giving $14+0.6e$. The total line voltage, 100 percent, is then equal to $\sqrt{(10+0.8e)^2+(14+0.6e)^2}$. Solving this equation, $e=82.2$. The regulation is then, $100-82.2$, or 17.8 percent as against 16.4 percent obtained by Mr. Peck's method.

184—CLEANING SWITCHBOARD PANELS—What is the best method of cleaning marble switchboards, removing grease spots, etc.? R. H.

If scratches are to be removed, smooth down with a block of pumice stone until the blemish is rubbed out. Polish with oxalic acid or with "polishing powder." If acid stains are to be removed, apply an ordinary blotter soaked in chloroform. Oil stains can be taken out by applying a layer paste composed of plaster of Paris mixed with benzine. Use a layer about two inches thick, leaving it on for about twenty-four hours. If the first application is not entirely effective, repeat the treatment. For cleaning slate boards, smooth down the surface if necessary with pumice and rotten stone. Finally, a polish should be put on with dry hands. Dirty boards should be cleaned simply with soap and water. Never use oil on the enameled surface.

185—Osnos Circle Diagram—Is the Osnos circle diagram for the repulsion motor used in commercial work as is the Heyland diagram for induction motors? What losses, if any, does it take into account? Can the no-load speed of the repulsion motor be determined otherwise than by means of the Osnos circle diagram? F. J. B.

The Osnos circle diagram is not commonly used in commercial work, it is much more difficult to get accurate agreement between theory and practice in any type of alternating-current commutator motor than in the induction motor, still more difficult in a motor with series characteristics, and most difficult of all, apparently, in the repulsion motor. In the induction motor the flux is constant, while in a motor with series characteristics, it varies with the load, and the varying saturation usually gives higher currents at low speeds than the diagram shows. The most important cause of variation, however, is the following: The alternating flux induces an e.m.f. in the coil under commutation which produces a current therein, and this current reacts on the field. This action is particularly intense in the repulsion motor at speeds above synchronism. It has the effect of reducing the power-factor a good deal and of causing the free speed to be much lower than the diagram indicates, often not more than one and one-half times synchronism. The foregoing applies to small motors, say five to twenty hp, for 60-cycle circuits, which are the only kind built at all extensively. No doubt the diagram would be fairly accurate, except for saturation, for large railway motors were any such being built. The Osnos diagram takes account of the secondary resistance only, all other losses being neglected. Diagrams have, however, been published, taking these into account (see Electrical Review, London, February 19, 1904), though none in which the effect of the commutating coil appears. F. C.

186—Current and Voltage Relations in Railway Circuits—I have noticed that with a given number of cars a certain railway feeder section will take more current when the voltage is low than when it is normal. Low voltage of course results in lower speed and consequently the power is less. Will the motors take more current when the voltage is low regardless of speed, and does it drop in proportion to the drop in voltage? R. R. Y.

With a number of cars drawing current from the feeder section the effect of a drop in the voltage would be to cause a decrease in the speed of the motors. In order that the cars should make their schedule it would, of course, be necessary that they keep the current on the motors during a longer total period of the run than when the voltage was at normal, the ordinary method of running the cars with the voltage normal being to accelerate the cars to full speed, then throw off the current from the motors, allowing them to coast through a certain distance and finally to apply the brakes for stopping. With a lower maximum speed as explained above, it would not be possible to make schedule time with a period of coasting such as referred to. Consequently with a given number of cars the condition would probably be that a large number of the cars would have current on during the total length of their respective runs from station to station and the total amount of power and likewise the total amount of current would be correspodingly greater, thus accounting for the condition noted. If but one car were involved in the question it would be found that decrease of voltage would result in decrease of current due to decrease in speed. C. R.